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29/2018

# Bridge WIM Overview Report
Year 2013–2017

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*Cover photograph: Finnish Transport Agency's photo archives*

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# Abstract

Subsequent to the agreement between the Finnish Transport Agency – FTA (Liikenne-virasto), Helsinki, Finland, and Trafikia AB, Sweden, weigh-in-motion measurements have been carried out on several road sections throughout Finland. The purpose of the measurements has been to obtain reliable information about the traffic loading, including axles, bogies and Gross Vehicle Weights (GVW) to demonstrate the system and to compare results achieved by Destia Ltd., Finland from a dynamic axle balance study.

Measurements reported here took place between September 2013 and October 2017, following a pilot measurement in 2007. A SiWIM Bridge weigh-in-motion system (B-WIM) as supplied and manufactured by Cestel d.o.o. Slovenia, was used on all the measurements. Data was analyzed using a Finnish specific vehicle classification table.

New vehicle regulations were implemented in Finland in October 2013, radically increasing the allowable Gross Vehicle Weights on the Finnish road network. Although this increase is thought to decrease the costs for transportation entrepreneurs the increase in GVW's is thought to have also a proportional detriment to the road infrastructure, increasing maintenance costs and reducing the projected lifespan of pavements and bridges. The information collected in this study will give an early indication of the latter affects and the trends of vehicle configurations, before and after the new regulations.

This report presents the measuring procedure, the details about the measurements, the vehicle classifications, the weigh-in-motion results for the measured periods and the evaluation and analysis of these results.

**Bridge WIM -raportti 2013–2017.** Liikennevirasto, tekniikka- ja ympäristöosasto. Helsinki 2018. Liikenneviraston tutkimuksia ja selvityksiä 29/2018. 153 sivua. ISSN-L 1798-6656, ISSN 1798-6664, ISBN 978-952-317-549-5.

**Avainsanat:** Sillat, tiet, ajoneuvot, raskas liikenne, mittaus, mittausmenetelmät

# Tiivistelmä

Liikennevirasto on teettänyt Trafikia AB:lla (Ruotsi) weigh-in-motion-mittauksia siltoihin sijoitetuilla BWIM-mittauslaitteistoilla muutamilla tieosilla eri puolilla Suomea. Mittausten tarkoituksena on ollut saada luotettavaa tietoa raskaan liikenteen painoista akseli-, teli- ja kokonaispainojen osalta, mittausmenetelmän demonstroimiseksi ja mittaustulosten vertailemiseksi dynaamisiin vaakamittauksiin (Destia Oy).

Tässä raportoidut mittaukset on tehty syyskuun 2013 ja lokakuun 2017 välisenä aikana. Samantyyppisellä järjestelmällä tehtiin pilottimittaus jo vuonna 2007. Kaikissa mittauksissa käytettiin SiWIM-silta-weigh-in-motion (BWIM) -järjestelmää, jota valmistaa Cestel d.o.o. Sloveniasta. Mittausdata analysoitiin käyttäen suomalaiselle raskaalle liikenteelle spesifioitua luokittelua.

Suomessa astui voimaa uusi ajoneuvoasetus lokakuussa 2013, joka lisäsi radikaalisti sallittuja raskaan liikenteen kokonaispainoja Suomen tiestöllä. Uudistuksen on laskettu vähentävän raskaan tavaraliikenteen kustannuksia tiestöllä. Toisaalta kokonaispainojen nousu tuo suhteessa haittaa tieinfrastruktuurille lisäten ylläpito-kustannuksia ja pienentäen mm. päällysteiden ja siltojen käyttöikää. Tämän tutkimuksen perusteella nähdään merkkejä jälkimmäisestä sekä voidaan nähdä myös trendejä ajoneuvoyhdistelmien muutoksesta ajoneuvoasetuksen muutoksen jälkeen.

Tämä raportti esittelee mittausmenetelmän, detaljitietoja mittausten suorittamisesta, ajoneuvoluokittelun, WIM-mittaustuloksia mittausjaksoilta sekä mittaustulosten analysointia.

**Bridge WIM rapport 2013–2017.** Trafikverket, teknik och miljö. Helsingfors 2018. Trafikverkets undersökningar och utredningar 29/2018. 153 sidor. ISSN-L 1798-6656, ISSN 1798-6664, ISBN 978-952-317-549-5.

# Sammandrag

Efter överenskommelse mellan Trafikverket i Helsingfors, Finland och Trafikia AB, Sverige, har vägning av tunga fordon (B-WIM, bridge-weigh-in-motion) genomförts på ett antal vägavsnitt i hela Finland. Målet med viktmätningarna har varit att få tillförlitlig information om trafikbelastningen, inklusive axlar, boggier och bruttovagnsvikter (GVW) för att demonstrera systemet och jämföra resultaten utförda av Destia från en dynamisk axelviktstudie.

Mätningar som rapporteras i detta dokument ägde rum mellan september 2013 och oktober 2017, efter en pilotmätning 2007. Det mätsystem som använts på alla mätplatser är ett SiWIM bro-vägsystem (B-WIM) som levereras och tillverkas av Cestel d.o.o. i Slovenien. Data analyserades med hjälp av en fordonsklassificeringstabell anpassad för Finland.

Nya fordonskrav infördes i Finland i oktober 2013, vilka radikalt ökar tillåtna vägtrafikvikter på det finska vägnätet. Trots att denna ökning tros sänka kostnaderna för transportföretagare, antas ökningen av tex. bruttovikter (GVW) också ge en negativ effekt på väginfrastrukturen genom att öka underhållskostnaderna och minska den projicerade livslängden på infrastruktur (väg/broar). Den information som samlas in i denna studie kommer kunna ge en bild av påverkan och trender för fordonskonfigurationer före och efter de nya reglerna.

I denna rapport presenteras mätproceduren, detaljerna om mätningarna, fordonsklassificeringen, viktresultatet för de uppmätta perioderna och utvärderingen och analysen av dessa resultat.

# Foreword

The weigh-in-motion (B-WIM) measurements undertaken in this project were an essential part of the study programme entitled the Axle Load Programme 2013-2014 (Akselimassatutkimukset 2013-2014). This study programme has now extended to include results from 2015 and subsequently 2017. Measurements conducted by Destia Ltd. from Finland by means of a dynamic balance test, were also included in the larger study. The steering group of the study consisted of experts from the Finnish Transport Agency as well as stakeholder group representatives from The Finnish Transport Safety Agency Trafi, The Association of Finnish Local and Regional Authorities, Finnish Forest Industries, Metsäteho Ltd., and Aalto University. The project manager of the WIM study at the Finnish Transport Agency was Timo Tirkkonen and for Trafikia AB the project manager was Hans Forsberg.

The results from this study can be used as a tool to project traffic loading and any potential reduction of infrastructure durability.

Helsinki November 2018

Finnish Transport Agency

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# 1 Introduction

## 1.1 Background

This report is produced by Trafikia AB in Sweden in co-operation with the Finnish Transport Agency, project manager for Engineering Structures, Timo Tirkkonen.

The report presents the SiWIM system, the measuring procedure, the details about the measurements, the results of the calibrations, the overview of the weigh-in-motion results for the measured periods per site, and the evaluation and analysis of these results.

All WIM measurements have been performed by Trafikia AB with Cestel doo. as sub-consultant.

List of Abbreviations:

| | |
|---|---|
| AGW | Actual Gross Weight |
| B-WIM | Bridge Weigh in Motion |
| COST | Co-Operation in the Field of Scientific and Technical research |
| ESALs | Equivalent Single Axle Load |
| FAD | Free of Axles Detectors |
| GVW | Gross Vehicle Weight |
| NOR | Nothing on the Road |
| TCF | Tyre Configuration Factor |
| TRV | Trafikverket (Sweden) |
| WAVE | Weighing-in-Motion of Axles and Vehicles for Europe |

## 1.2 Purpose of the study

The purpose of the measurements was to obtain reliable information about the traffic loading, including axles, bogies and Gross Vehicle Weights (GVW) to demonstrate the system and to compare results achieved by Destia Ltd., Finland from a dynamic axle balance study.

This report concentrates specifically on the results from the Trafikia AB measurements, and a combined comparison report will be produced at a later date.

The weigh-in-motion (B-WIM) measurements undertaken in this project were an essential part of the study programme entitled the Axle Load Programme 2013-2014 (Akselimassatutkimukset 2013-2014). This study programme has now extended to include results from 2015 and subsequently 2016.

New vehicle regulations were introduced to Finland in October 2013 under FINLEX regulation 407/2013, clauses 20§ to 30§ raising the GVW of an 8-axle vehicle (meeting loading and wheel configuration criteria) to 64 tons and a 9-axle vehicle (meeting loading and wheel configuration criteria) to 76 tons. Also within the regulations, a stipulation that a triple axle (subject to wheel configuration and axle distances) was raised from 24 tons to 27 tons. New regulations were also implemented for 2 axle bogies (subject to wheel configuration and axle distances) and for 3 axle and 4 axle trucks, also meeting similar criteria.

# 1.3 Bridge Selection

This section explains how the inventory of suitable bridges where done, important parameters, road sections and a short note on road network loading model. Most Finnish bridges are suitable, depending on the bridge and pavement quality, for WIM measurements.

During July of 2011, an inventory was taken of bridges in the North of Finland including sections of the E8, roads 80 and 79, from Pajala in the Eastern region of Sweden running to Kittilä and Sodankylä and following the E63 to Pelkosenniemi before returning to the E75 through Rovaniemi and joining the E8/E75 at Kemi to continue southwards through Oulu, Jyväskylä and Helsinki.

In the south, the inventory took a route following the old E18 east of Helsinki and circling first northerly to Kouvola and then easterly taking road 6 to the junction with road 1/E18 continuing to Turku in the west of Finland.

The main reason for the inventory, was to establish an overview of the bridge design, commonality of the bridge types and of course suitability for WIM measurements.

Since this first road bridge survey was completed, further surveys on roads E8 from Vaasa to Pori (Bridge selection at Pirttikylä), the E9 from Kuopio to Riistavesi (with attention to Jännevirta) and the E75 from Lahti to Järvenpää (with attention to Mäntsälä) was done.

From the above inventory and with further specific site visits the following bridges were chosen for measurements year wise (Table 1):

*Table 1. Chosen bridges for B-WIM measurements in Finland 2013-2017.*

| Location | Bridge id | Road No. | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| Tesjoki | | E18 | X | | | | |
| Olhava | | E75/E8 | X | X | X | X | X |
| Kaarina | | Road 180 | | X | | X | |
| Ring III East | | Rr 3 | | X | X | | X |
| Ring III West | | Rr 3 | | X | X | | X |
| Pirttikylä | | E8 | | X | | | |
| Äänekoski | | Hw 4 | | X | X | X | |
| Mäntsälä | | Hw 4 | | | | X | |

### 1.3.1 Parameters

A clear majority of bridges are suitable for WIM measurements, but it is vital to specify and understand the user requirements before selecting a bridge. Even if characteristics for suitability are not fully fulfiled, proprietary software, supported by advanced algorithms, elaborated calibration and post-processing procedures, considerably extends the range of suitable structures.

Algorithm, hardware and software design and implementation allows the B-WIM system to instrument different types of bridges, ranging from short slabs to very long span bridges. An important bridge selection factor is its ability to perform bridge WIM measurements without axle detectors (Free-of-Axle Detector or Nothing-on-the Road).

Characteristics that define suitability for bridge WIM measurements include the bridge structural material, bridge and/or span lengths, boundary conditions, thickness of the superstructure, type of structure, and susceptibility to temperature effects, road roughness, skew, and susceptibility to dynamic loading.

### 1.3.2 Terminology

Before describing any type of bridge, the basic terminology should be explained. For most used bridge types, slab and girder bridges, bridge superstructures can be either:

- **Slab** (structural)/deck (as a part of the bridge), which can be:
  - Monolith/cast in place, this is using concrete and armoring materials in shuttered constructions.
  - Prefabricated, where the bridge parts are factory made and assembled on site.
- **Beams** (concrete) or girders (steel) in either I or T shape, or as a box (main beams or girders in the shape of a hollow box).
- **Box Girder**
- **Orthotropic**

The easiest to install are concrete slab bridges. Their main advantages are as follows: they are short and slender, they allow more accurate calculation of single axles and axles of a group, which generally increases the overall accuracy class of the measurements, they are easy to instrument and maintain and in many countries, they are the predominant type of the bridge, comprising over 60% of the overall bridge stock.

Due to their relative slenderness and typically shorter spans, they are likely more susceptive to temperature effects, especially if the structure is of the integral type, damaged (cracked) or located in the areas with high temperature fluctuations.

The superstructure of a girder/deck bridge typically consists of two main elements, steel girders or concrete (reinforced or pre-stressed) beams and concrete or steel deck placed over them. Their main advantages over slab bridges are as follows: they are generally longer than slab bridges, they allow more accurate estimation of the gross weights and strains are easier to measure than on slab bridges, since all the stresses due to traffic loading are concentrated in beams/girders in the longitudinal direction. They also exhibit less temperature dependence as regards of the variations of stiffness of the pavement.

The deck is the roadway portion of a bridge (the top side of the bridge), including shoulders (the part of the road, where driving is not permitted), sidewalk (the part of the bridge, where pedestrians and cyclists are located), pavement or carriageway (where vehicles are located), longitudinal (in the direction of driving) and transverse or expansion joints (between sections of the bridge). Important parts of bridges are the waterproofing (membrane), reinforcement and prestressing cables.

Bridge substructure consists of all the parts that support the superstructure. The main components are abutments or end-bents, piers or interior bents, footings, and piling. Abutments support the extreme ends of the bridge and confine the approach embankment, allowing the embankment to be built up to the planned bridge deck.

Three main factors are used in describing a bridge. By combining these terms, one may give a general description of most bridge types.

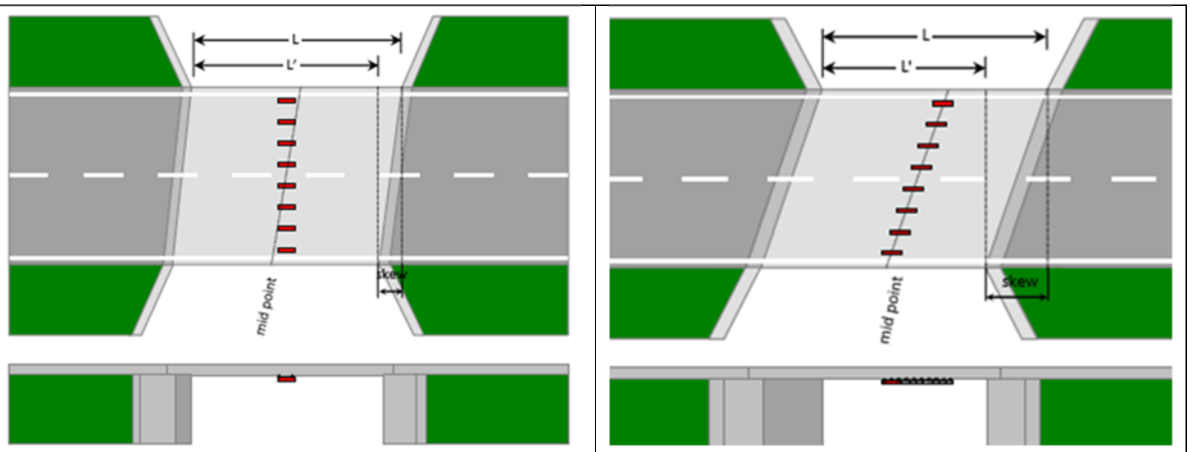
- **span:** simple, continuous, cantilever
- **material:** stone, concrete (reinforced/bars, pre-stressed/cables), steel, cast iron, timber/laminated elements, plastics, etc.
- **form:** beam, girder, arch, suspension, etc.

From the above, there are many types of bridge, but wherever possible, we prefer to use a simply supported slab type bridge as described below.

### 1.3.3 Bridge skew

A skew down to 80° (90° denoting the road axis perpendicular to the abutments) has negligible effects, and a skew down to 70° has minor effects on the accuracy of results. Experiences indicate that after checking the test measurement and calibration data, even angles down to 45° are acceptable. Skewed bridges however require additional attention during installation and calibration. In B-WIM terms, a bridge is considered “straight” if the skew covers less than 20% of the instrumented span. With width of the bridge equal to the instrumented span, this corresponds to a skew angle of approximately 79° and decreases with increasing ratio width vs. length of the bridge.

On the other hand, if the skew covers more than 20% of the instrumented span, the bridge is considered “skewed”. Then the installation and calibration procedures require special attentions and the bridge instrumentation should be done in a different way.




| Recommended placement of strain transducers for straight (low-skewed) bridges | Recommended placement of strain transducers for skewed bridges (skew > 20 % of instrumented span) |
|---|---|

*Figure 1. Recommended placements of strain transducers for straight and skewed bridges.*

In all aspects of bridge selection, it is important to remember that it is the traffic over the bridge that is being measured, and the bridge itself is merely the instrument to conduct these measurements.

### 1.3.4 Criteria for selecting bridges for B-WIM measurements.

There are a few general rules on selecting appropriate bridges for B-WIM measurements.

It is vital to specify and understand the user requirements, i.e. what quality of results (accuracy and percentage of weighed vehicles) is needed. Less demanding applications, such as collections of traffic load statistics, require lower accuracy of results and thus allow a wide selection of appropriate structures. On the other hand, B-WIM measurements are in some countries used also for pre-selection for the weight control of heavy vehicles carried out by police when the accuracy demand may be quite high.

Bridges should be placed in an open road with fluent traffic. Locations close to junctions or railway crossings with a significant proportion of stop-and-go traffic are, as for any other WIM type, less appropriate or inappropriate. They may be acceptable only where accuracy requirements are low.

Bridges with smoother approaches, without bumps in front of the measured span, will give more accurate results.

For most FAD installations (exceptions being longer span bridges with cross beams that are evaluated one-by-one), the optimal span lengths are in the range of 6 to 12 meters for single-span bridges and any length up to 12 m per span for multiple span bridges.

As bridge WIM systems evaluate axle loads from the overall effect of all axles being on the bridge at a given time, presence of more than one heavy vehicle on the bridge at the same time affects accuracy of the results. Values obtained from the real measurements, suggest the conclusion that on roads with less than 1000 heavy vehicles per day and span lengths not exceeding 10 m, less than 1% of such events can be expected.

Older or deteriorated structures require special attention during installation, for example, to avoid installing strain transducers near cracks in concrete.

### 1.3.5 Network WIM extrapolation

The data collected by the B-WIM system is specific to that road section, but by extrapolation of the results and by using nearby static/long term traffic counters (LAM systems in Finland) load bearings for arterial roads can be calculated by factorization. It must be understood that this will produce a limited accuracy as the traffic flow cannot be automatically assumed as consistent with that flowing through the B-WIM measurement point, and that the further the static measure point is from the B-WIM measurement the lower the expectation of accuracy or dependency on the results. To improve these limitations, it would be necessary to have a network of B-WIM results to further complement the static measures, and thereby improving the model of the network loading of heavy traffic.

It must however be noted, that not every road section will have a bridge suitable for B-WIM measurement.

# 2 Measurement system

## 2.1 Background of the measurement system

### 2.1.1 Weigh in motion systems

Weigh-in-motion (WIM) systems have been traditionally used to collect freight traffic data to support transportation planning and decision-making purposes. As high axle loads are responsible for road and bridge damage, the aim of any WIM system is to obtain accurate axle load and gross weight information. Despite the fact that dynamic interaction between the vehicles and the pavement affects accuracy of WIM results, weighing in motion is well recognized as the only weighing method which can measure the entire population of vehicles on a road section, including the overloaded ones which easily avoid other modes of weighing. It is therefore the most efficient way of providing unbiased data on the heavy freight vehicles.

### 2.1.2 Bridge weigh in motion systems

Bridge WIM (B-WIM) method was developed by Prof. Moses and his team in 1979. They proposed and implemented a new idea to use existing instrumented bridges from the road network to weigh vehicles in motion. Despite many advantages, B-WIM did not play an important role on the WIM market. It became really popular only in Australia where 200 systems are in operation using culverts instead of bridges,. Two additional B-WIM prototypes, based on Moses' theory, were developed in 1990's independently in Slovenia and in Ireland. A major step forward in B-WIM technology was done in the late 1990's as a result of extensive research performed in two European projects: the COST 323 action "Weigh-in-Motion of Road Vehicles" [COST 323, 2002] and especially in the Work Package 1.2 of the European Commission 4th Framework Programme research project "WAVE – Weighing of Axles and Vehicles for Europe" [O'Brien & Žnidarič, 2001].

### 2.1.3 SIWIM system

ZAG, the Slovenian National Building and Civil Engineering Institute, developed the first SiWIM system prototype in 1997 in order to fulfil the WAVE project objectives. It was composed of software written in Borland Delphi programming language and of gradually developed electronic components. It presented the first step towards a new generation of bridge WIM systems. After conclusion of WAVE in 1999 development of SiWIM continued. Software and hardware were upgraded to Version 1, which enabled unattended several day-long measurements. Data was acquired and processed by a notebook computer. The end of 1999 initiated cooperation between ZAG and the Cestel Company, with the main goal to commercialize the SiWIM prototype. SiWIM 1.0 in year 2000 was based on a completely new modular hardware installed in weatherproof side-road cabinet. The new software among others featured remote control through a mobile phone line and provided hourly data reports on the Internet. Data was acquired and processed with an industrial MS Windows® NT based computer.

Since this initial system was conceived, many advances and developments have taken shape, both in hardware and software, and the most notable aspects are:

- 2003 - introduction of FAD (free of axle detectors).
- 2006 - implementation of camera system, Wi-Fi and VPN network viewers.
- 2009 - MKIII hardware - total re-development of components and system.
- 2011 - Development of MKIII software.
- 2014 - Commercial launch of MKIII software.

### 2.1.4 Cestel - Vägverket (Swedish Transport Administration) - Vägverket Konsult, Vectura, Sweco, Trafikia - FTA (Finnish Transport Administration)

In the late 90's, after the theories of Weigh-in-Motion had been proven, the Swedish Transport Administration were involved in a number of preliminary tests using strip sensors, placed on the road, and coupled to a monitoring system. Although now deemed primitive, the concept was registered as having significant potential, and when the commercial system was developed a number of pilot tests were conducted in Sweden in 2002. This led to the procurement of a contract for a network of measurements to be undertaken within the Swedish road network, under the auspices of ITSS (International Transport Safety Standards), then a division of STA.

In 2003 a National and Regional measurement survey was agreed, being at that time a total of 28 measurements to be performed annually, the National selections to be fixed and the regional selections to be mobile (depending on the interest of the various regions). Vägverket Konsult, then under the umbrella of STA, were to be the installers, responsible for the system installation, data collection and data analysis. This national measurement has continued until the present day.

With the de-nationalization of Vägverket in 2009, Vägverket Konsult became Vectura and subsequently was amalgamated with Sweco in 2014. This association was short lived and the Traffic Information and Analysis department became an independent company called Trafikia AB. Although the name has changed, relatively few changes have been made to the personnel of the company, and as a company involved in WIM measurements since 2002 we have developed a strong and vastly experienced team. Through extensive training and field experience, our staff have helped to develop the SiWIM system, together with Cestel, competently and with foresight for future customer requirements.

The relationship with Cestel d.o.o. has been established for over 15 years now and our working co-operation is very sound. Trafikia AB are the Nordic agents for Cestel, and Cestel are Trafikia's sub-contractors responsible for the raw data analysis. After an initial visit by FTA to a test site in Storvik, Sweden, Cestel were invited to undergo a pilot test of the SiWIM system on the road E18 near Espoo in Finland in 2007. Further development talks were held, leading to the inclusion of B-WIM measurements to be performed by Trafikia, in the Axle Mass Programme 2013-4. This has now extended to include measurements from 2015 to 2016.

## 2.2 The SiWIM B-WIM system

The SiWIM® Bridge weigh-in-motion system consists of three parts: hardware, software and trained personnel.

The hardware is designed around a processing unit capable of collecting and storing, in real time, all raw signals measured by the strain transducers installed on the soffit of the bridge.

The embedded software allows processing of traffic in several traffic lanes according to the user's needs. The software suite consists of three main modules:

- **Engine**, a standalone data acquisition and processing module,
- **Frontend**, used to setup, monitor and maintain the system, and
- **Data Processing** software, used to reprocess data and to generate results for various applications.

The most important part of the SiWIM system is the people. With their expertise and proper training, they perform measurements and create reports and analyses, using collected data.

### 2.2.1 Hardware, Identification of Components.

Based on simple strain gauges, precise amplifiers, fast signal converters and a reliable computer, the SiWIM system is a set of basic components, which together form a high-tech, advanced, reliable and scalable system for use in a wide range of different situations.

**The Cabinet**

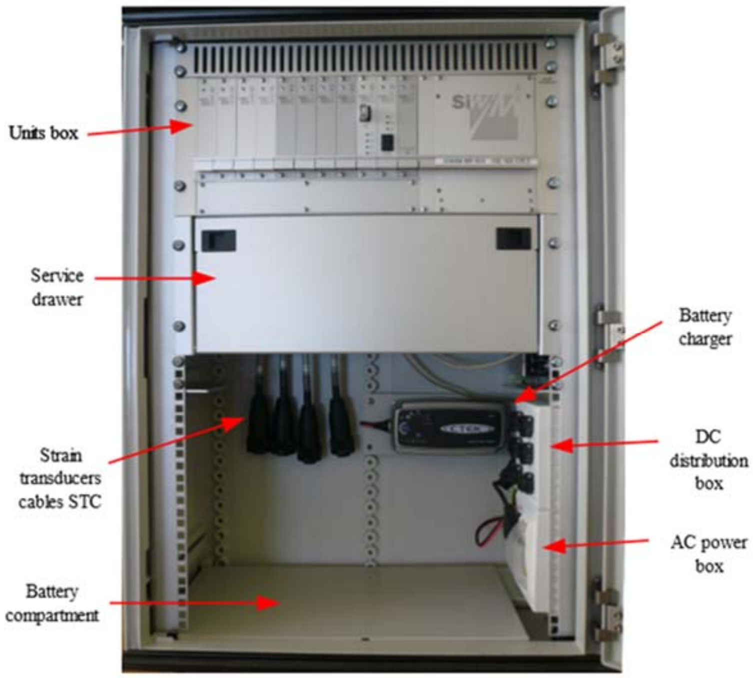



*Figure 2. Cabinet of the SiWIM® system.*

Starting from top, the cabinet contains SiWIM unit box, service drawer and battery compartment. On bottom right are DC distribution box, AC power box, battery charger and ethernet switch. On the cabinet bottom right are the cable outlet and external network connector.

**Units Box**

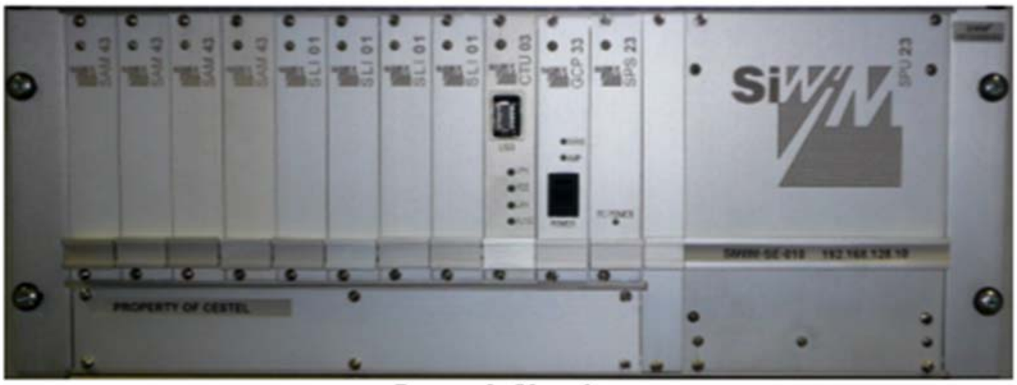



*Figure 3. Unit box of the SiWIM® system.*

SiWIM units box is made up of 11 slots and computer compartment. Starting from left there are 8 amplifier slots, each handling four sensors channels. Each channel has its unique number (example: slot 2 has channels from 5-8, slot 3 has channels 9-12). Slot 9 belongs to CTU-03 control unit, slot 10 to GCP-33 power supply and slot 11 to SPS-23 computer power supply. On the far right is the processing unit SPU-23.

**AC Power Box**

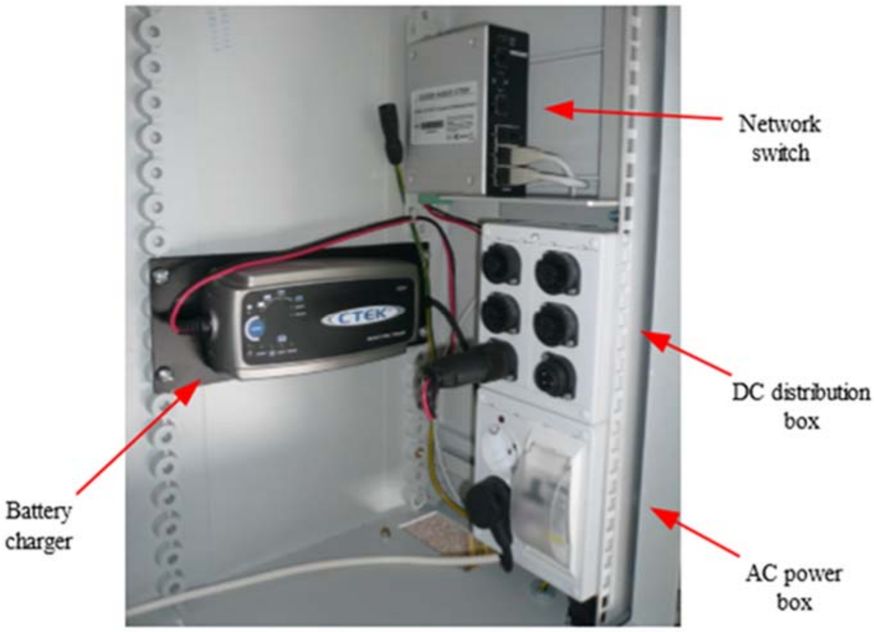



*Figure 4. AC Power box, DC distribution box, network switch and battery charger of SiWIM® system.*

AC power box consists of an over voltage protection, resettable 6A fuse and two 220V sockets. One socket is used for battery charger.

**DC distribution box**

DC distribution box consists of 6 connectors that distribute 12V across various system devices. The lowest two male connectors are used for charger input and battery. The other supply the unit box and PUC-02. The upper left connector is intended to supply external router. This 7-pin connector includes network link connected to Ethernet switch.

**Ethernet Switch**

Above the DC distribution box (see picture 3) is the network switch. For standard operation, these devices are connected:

- Units box
- PUC-02 (4 connections)
- DC distribution box (for external router)
- External cabinet connector

**BCH-01 (Battery charger)**

BHC-01 purpose is to supply the system with 12V and to keep the lead acid battery charged.

**ST-503 Sensor - Strain Gauge**

Each strain transducer is equipped with 4 strain gauges in a full Wheatstone configuration. They measure strains, i.e. elongations and compressions of the structure ($\Delta L$) between the two anchors placed approximately 200 mm apart (L), under the load applied. Strain transducers are bolted into steel anchors fixed in holes in concrete or on steel mounting plates glued onto the surface of the bridge.

When a vehicle passes the bridge, the structure bends under the weight of the vehicle. Strains due to bending are measured with ST-503 strain transducers (Figure 5). Electric signals are transmitted to the SiWIM® processing unit through a network of cables and interfaces.

SiWIM® system uses up to 32 strain transducers, connected in groups of 8 through SSP-83 8-channel signal collectors. They feed their signals through a single cable connected to the SiWIM® processing unit, in order to provide installation with a minimum number of cables hanging from the structure. Each SSP-83 also connects one temperature sensor to the system.

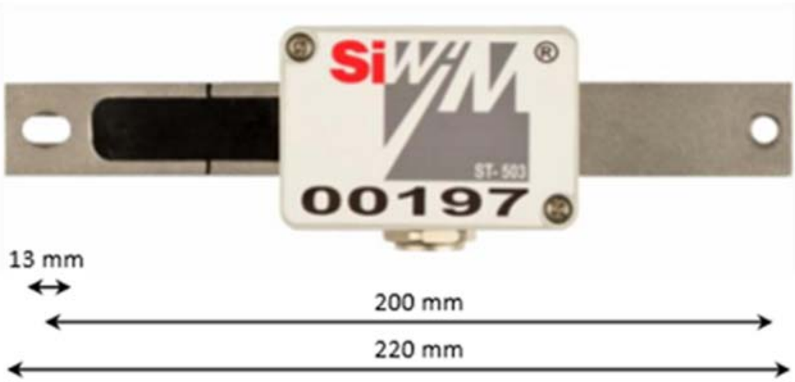



*Figure 5. ST-503 strain gauge sensor of the SiWIM® system.*

Normally 16 sensors are used on a typical 2-lane bridge. 12 "weighing" sensors distributed normally on the center-line of the bridge, with 4 sensors acting as free of axle detectors.

Prior to installation, the bridge is measured for breadth, length and pavement thickness. These are the physical dimensions. The pavement and road markings are also measured, this determines where the vehicles will be running over the bridge, and by observation (both visual and by sustained deformation of the pavement) the optimum impact of the vehicle tyre/axle loads. From this information, the installation (or array) is configured, placing sensors in calculated locations under the bridge to maximize signals from the traffic above. The same information provides specific locations for the FAD sensors, being placed directly under the wheel tracks of the passing vehicles.

The array is translated to the SiWIM-F and a digital representation of the sensor placement is made. This array is individual for all bridges, and an example is shown below (Figures 6 and 7):

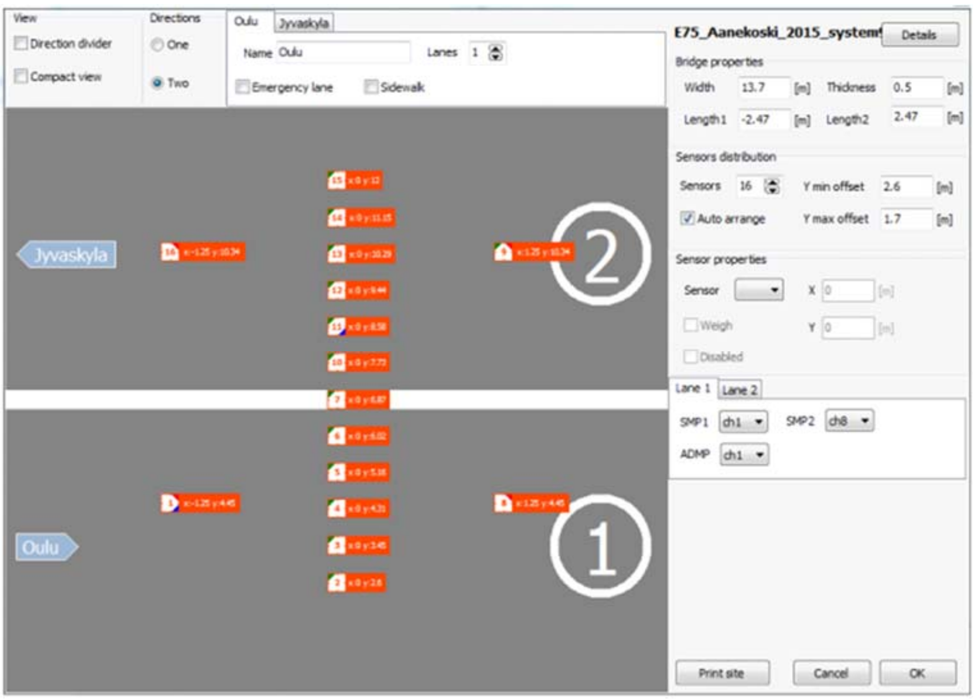



*Figure 6. Digital representation of the sensor placement (E75/Äänekoski bridge).*

*Figure 7. Photo from the sensor placement of E75/Äänekoski bridge.*

Especially on longer stiffer spans (e.g. girder/deck bridges), the level of strains due to light axle loads can reach only a few micro strains ($10^{-6}$ m/m). Thus, a very precise signal conditioning system is required, which:

- must sufficiently amplify the very weak strain signals,
- should not introduce electrical noise,
- should not introduce electro-magnetic noise as a result of using wireless add-ons, such as mobile phones and wireless network systems.

The FAD B-WIM installations are considerable more durable than the conventional axle detectors (tubes) as the sensors are hidden under the bridge and are not exposed to traffic. Unfortunately, on some types of bridges the instrumentation with strain transducers under the wheel track does not provide satisfactory results. But, where possible, a FAD installation completely eliminates all actions on the pavement.

To understand which structures qualify for FAD measurements, it is necessary to understand the parameters which influence strain response under the moving vehicle. These are:

- shape of the influence line.
- ratio between the span length and the (shortest) axle spacings.
- thickness of the instrumented superstructure.
- dynamic interaction of the vehicle-bridge system.

For a successful FAD installation, it is essential that the influence lines are calculated as accurately as possible, i.e. directly from the measured strain signals.

Longer instrumented spans are more difficult to use for distinguishing individual axles. Even on thinner superstructures the contributions of individual axles are difficult to recognize in the total strain response when the ratio between the shortest axle spacing and the span exceeds 8. If axle peeks cannot be seen clearly, additional sensors on the slab or on other secondary elements are needed.

Thickness of the superstructure defines:

- sharpness of the peaks, i.e. to what extent the measured strain peaks are smoothed out, and
- flexibility of super-structure.

When the ratio between the width of a peak of the influence line, $P_w$, and its height, $P_h$, is more than 2, then the percentage of the closely spaced axles, which can be identified, decreases rapidly. The Figure 8 below shows that $P_w$ and $P_h$ depend on the shape of the influence line, the length of the span and the thickness of the superstructure. For this reason, on longer spans additional sensors on the thinner and shorter structural elements are required to obtain the well-defined axle peaks. These factors can be summarized in the FAD coefficient:

$$FAD = \frac{LxH}{d_{min}x\ f_i}$$

where:
L - length of a span,
H - thickness of the superstructure,
$d_{min}$ - minimal axle spacing and
$f_i$ - factor of the influence line, defined according to the Figure below.

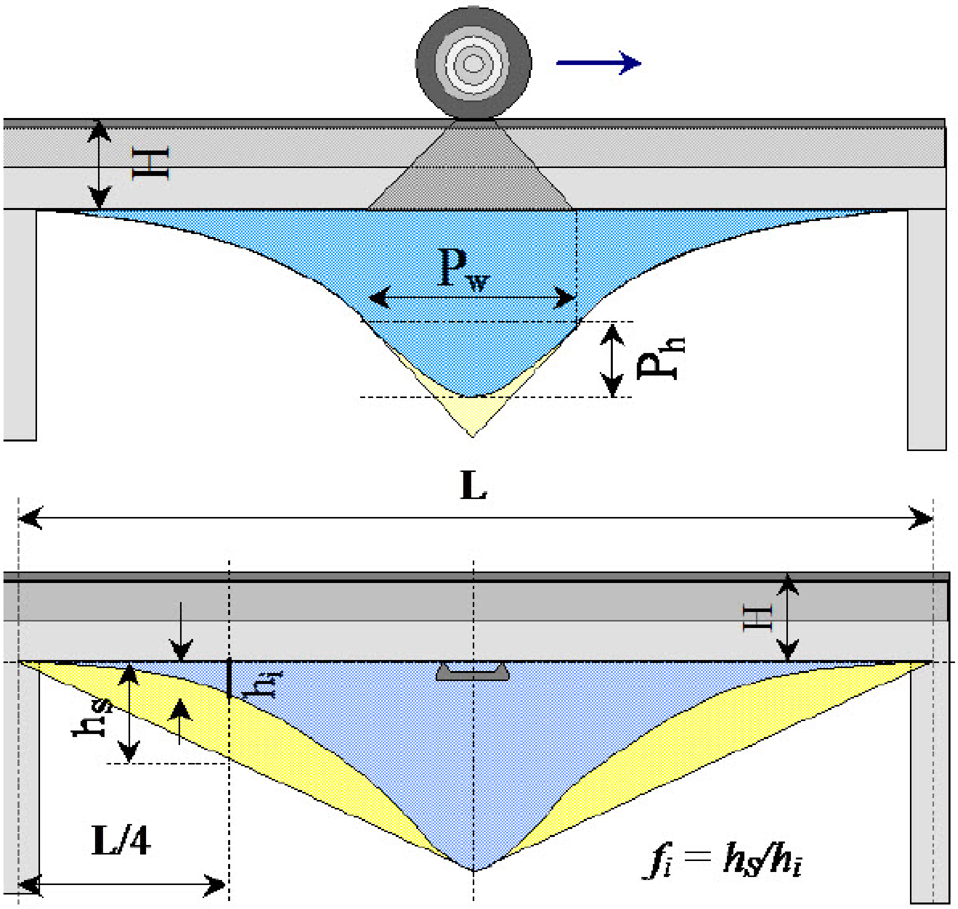



*Figure 8. Effect of the superstructure thickness on the peak of influence line.*

The tests show that a span can be used for FAD measurements without sophisticated post-processing or additional sensors on the slab if the FAD coefficient is less than 2, conditionally (after performing test measurements), if FAD coefficient is less than 4. Following the above rules, the good candidates for FAD B-WIM instrumentation are:

- short span, frame-type slab bridges with typical $f_i$ factor around 3 and FAD coefficient between 1 and 2, and
- longer span bridges with thin slab supported in the lateral direction by cross beams or stiffeners (orthotropic, beam/deck, or similar bridges) with FAD coefficient below 0,5.

**SSP-83 Accumalator (Signal Collector)**


*Figure 9. SSP-83 accumulator (signal collector) of the SiWIM® system.*

Primary purpose of SSP-83 is to collect signals from several ST-503 strain transducers and channel them into a single STC cable connected to units box. Each signal collector offers a connection for STS-13 temperature sensor.

**STS-13 Temperature Sensor**

Temperature sensors measure the temperature of the structure and of the pavement. Temperature readings are applied to compensate temperature effects that occur on some types of bridges. One temperature sensor per every 8 input channels can be connected and up to 4 temperature sensors can be used in the system. An additional temperature sensor is installed inside the cabinet to measure internal temperature of the hardware.

Connected to SSP-83, the sensors measure temperature of the bridge and/or surrounding air. System supports up to 4 temperature sensors.

*Figure 10. STS-13 temperature sensor of the SiWIM® system.*

**SPU-23 Processing Unit**

In the SPU-23 processing unit, the signals are conditioned in 4-channel SAM-43 signal conditioning units, which acquire, amplify and process the signals. The system continuously calculates signal offsets that arise due to the extreme amplification of the signals and temperature effects, and zeroes them when the offset exceeds predefined thresholds. Depending on its configuration, the SiWIM® system accommodates up to 8 SAM-43 units, to condition up to 32 strain channels. A typical system is delivered with four SAM-43 units for 16 strain channels. Each SAM-43 unit is calibrated, and this is clearly marked on the centre of the board. With systems comprising less than 32 channels, sling boards SLI-03 short-circuit vacant channels to the ground, in order to eliminate noise on the data acquisition system input side.

Analogue signals are processed by the SiWIM® SPU-23 processing module designed around an embedded personal computer running the Windows® operating system, analogue to a digital converter and a hard drive. The system is configured remotely through an Ethernet or wireless link.

**Block Overview**

The diagram in figure 11 below represents the block diagram of the SiWIM system. The output signals from ST-503 strain transducers are being gathered by SSP-83 signal collector. Collected signals are routed through SAM-43 amplifiers to BMC digital analog converter board inside the SPU-23 unit. Additionally, the BMC digital output controls the zeroing and test function of the SAM-43 amplifiers. The other component of the SPU-23 unit is an industrial computer, which processes and stores data. The computer-bus interface is made up of RS232, feature cable, and two USB 2.0 buses which take care of the diagnostic LEDs, computer control, data storage, software key, voltage and temperature information. The SPS unit supplies the computer. GCP supplies sensors, amplifiers and digital circuitry. Hysteresis block switches off in case of a system low voltage. On the front of the module are voltage presence LEDs and main power switch. CTU's main function is system monitoring and control as well as USB data key feature and pneumo signal shaping. The front end of the unit consists of system status LEDs and the USB data key slot.

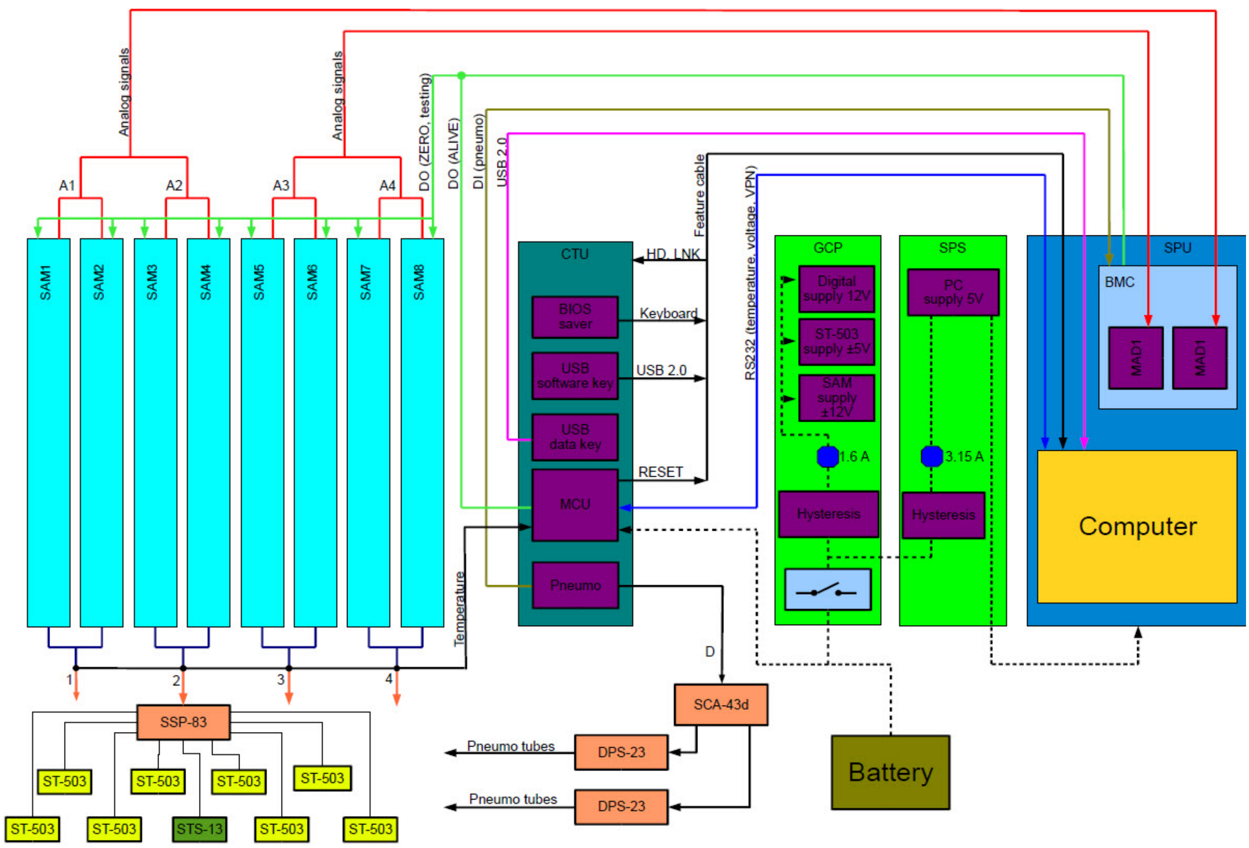



*Figure 11. The block diagram of the SiWIM® system.*

### Cameras and VPN

Cameras are attached and powered through the PUC-02 Camera Power Supply unit, which connects up to four cameras. This unit also provides additional hard disk space for storing photos from the measurements. Cameras are connected to the main unit through a single cable and can be equipped with infra-red reflectors for night vision.

An external HSUPA (HSDPA/UMTS/GPRS) router EXR-03 connects the SiWIM® system through a dedicated VPN connection over a mobile network, in order to remotely control the system and to back up data. This connection also allows for data transfer to remote hand-held PDA units using proprietary software. EXR-03 consists of a HSUPA router, wireless access point and GPS. Wireless capability enables the on-site team to connect thru a wireless network. The integrated GPS is used for providing exact location and for support during system calibration.

### 2.2.2 Software

The proprietary software is divided into areas of collecting, adjusting, processing, controlling, analyzing and presenting data, and is designed with the user in focus. Sophisticated algorithms are used to significantly ease up all necessary processes, while retaining on demand access to all parameters with extreme expandability.

There are three main programmes:

**SiWIM® Engine (SiWIM-E)** is a standalone application that runs on the on-site computer and performs and evaluates the measurements, calculates influence lines and stores raw and summarized data on the vehicles. It also collects activity, warning and other messages in the log and transmits them to the Front-End.

**SiWIM® Front End (SiWIM-F)** adjusts weighing parameters, displays the results, and serves for site calibration, on- and off-site control and data collection.

**SiWIM® Data processing software** (SiWIM-D) is used for post-processing and evaluation of measured data.

Two additional applications are used, namely:

**Supervision software (SiWIM-S)** which provides web-based comprehensive checking, control and off-site analysis of the systems present, together with alarms processed by the software. It also provides a backup facility for aggregated data from all measured sites.

There is also a **monitoring software (SiWIM-M)** which is another web-based application used for preselection. It feeds the live traffic data flow from a connected site to a web browser.

The two main programs (SiWIM-E and SiWIM-F) constitute the core of the system. They communicate with each other through the TCP/ IP (network) protocol.

The Engine (SiWIM-E) is designed around several modules connected through the TCP/IP protocol. They mostly run in individual threads, with the data acquisition thread having the highest priority, followed by the data evaluation (weighing) thread and the lower level threads, such as the ones for displaying of the results, for management of log files, etc. Even for the high volume traffic, the engine processes up to 32 input channels with real-time filtering. After being set-up with the SiWIM-F, the SiWIM-E runs without human attendance. Its main tasks are to acquire data from the strain transducers, to process the signals, to calculate the influence lines, axle loads, axle spacings, vehicle classes and categories, and to process and transmit data to SiWIM-F. All errors or questionable events that occur during execution are stored in a log file.

SiWIM-E stores data in its native NSWD format, as described below, which was developed according to recommendation of the European COST323 in 2001. NSWD files are written as text files and contain data about each individual vehicle. In addition, measured strain and axle detectors signals of each loading event can be stored as binary acquisition NACQ files. These are typically used to reprocess data, e.g. during the calibration process, or for double-checking overloaded or otherwise suspicious vehicles.

SiWIM-F (SiWIM Front-End) is as a standalone program to maintain the SiWIM Engine. It provides tools to setup, adjust and calibrate the site, to display the results received from the SiWIM Engine, to troubleshoot the SiWIM Engine parameters, to calculate the experimental influence lines, to synchronize (download) data with the SiWIM Engine and to reprocess measured strain signals.

**NSWD**
SiWIM® system stores data in its own text format (NSWD files) which contain the following information about each individual vehicle:

- Road section
- Number (ID) of the instrumented bridge
- Date
- Exact timestamp (hour, minute, second) of the passing vehicle
- Vehicle category according per specified classification based on axle spacing (unlimited number of categories)
- Axle loads
- Gross vehicle weight
- Axle spacing
- Length from the first to the last axle
- Temperature from 2 sensors
- ESAL value of the vehicle

This NSWD file is represented as an excel file, and for easy reference the Table 2 below can be applied to read the column information.

*Table 2. Column information of the NSWD file in the SiWIM® system.*

| Field | Data | Comments and units |
|---|---|---|
| 1 | Timestamp | Format is YYYY-DD-MM-HH-MM-SS-mmm |
| 2 | Offset | [s], measured from start of corresponding `.nacq` file |
| 3 | Site ID | |
| 4 | Session ID | |
| 5 | Warning flags | See table 4 for meaning of these |
| 6 | Lane | |
| 7 | $v$ | [m/s], speed |
| 8 | $N$ | Number of axles |
| 9 | Subclass ID | |
| 10 | Axle groups | E.g., 113 for a semitrailer |
| 11 | $W_{GV}$ | [kN], gross vehicle weight |
| 12 | $W_1$ | [kN], axle 1 load |
| $\vdots$ | $\vdots$ | $\vdots$ |
| $11+N$ | $W_N$ | [kN], axle $N$ load |
| $12+N$ | $\sum_{i=1}^{N-1} A_i$ | [m], total axle distance |
| $13+N$ | $A_1$ | [m], distance between axles 1 and 2 |
| $\vdots$ | $\vdots$ | $\vdots$ |
| $11+2N$ | $A_{N-1}$ | [m], distance between axles $N-1$ and $N$ |
| $12+2N$ | $T$ | [$^0$C], temperature used for compensation |
| $13+2N$ | Impact Factor | |
| $14+2N$ | $1000 \cdot Q$ | Quality estimate |

### 2.2.3 Installation

The installation procedure consists of attaching strain transducers for weighing and axle detection to the soffit of the bridge, usually at the location of maximum bending moments. Then, all sensors are connected through cables to the cabinet, which is attached to the bridge abutment. After being configured, the system monitors, collects and transfers data according to the requirements. All without interfering or even stopping the traffic or any intrusion into the pavement.

The sensors are attached to the bridge soffit by means of anchors in holes. The accumulator (commonly called "the Spider") is also located on the soffit. Cabling is connected from the 8 arms of "the spider" to the sensors, and as a typical set-up is 16 sensors, this pattern is repeated for a two-lane carriageway. The signals are then carried from the accumulator, by means of 28-pin cables, to the cabinet. A temperature sensor is also attached to the accumulator.

The selection of location and installation of strain transducers depends on the type of the superstructure. On beam/girder bridges, one or two transducers per beam are used. On slab bridges, they are placed at equal distances from one end to the other, with distance determined by depth of the superstructure. The longitudinal location is typically at the point of maximum bending moments, which on the single span bridges roughly coincides with the mid-span. On multiple-span bridges, the span closest to the abutment is usually best accessible for instrumentation.

Routers and aerials are connected to the system, enabling network connections.

The power supply is connected to the system as 220/240V direct supply or by routing it through the back-up battery. Where guaranteed constant power is supplied, the battery is rarely used. The GCP unit supplies all system required voltages 5V/12V except the computer.

Once all the hardware is installed, the system is switched on and a number of LED's indicate the status of the system.

The unit front consists of a USB data key slot and four LEDs (VPN, HDD, LNK, ALIVE).

- VPN – indicates connectivity with the VPN server. CTU software periodically pings VPN server and sends the resulting information over RS232 to MCU block. VPN LED is turned on when ping is successful.
- HDD – indicates hard disk activity (LED is computer driven through feature cable).
- LNK – indicates local network presence (LED is computer driven through feature cable).
- ALIVE – blinking indicates that SiWIM engine is running. ALIVE signal is generated by SiWIM engine that runs on the computer. In case of engine failure ALIVE LED remains static (either ON or OFF position). MCU initiates a computer reset when ALIVE signal is not alternating for 15 minutes.

Configuration of the parameters is performed through proprietary SiWIM-F software and consists of two stages – a) parameters setup and b) system calibration. Parameter setup typically takes less than an hour, after this, the system is fully functional and is collecting data. Calibration on a typical installation can be performed on any day of the measurement, since all data can be recalibrated during post-processing.

## 2.3 Calibration

In order to avoid significant errors in determining the load undergone by a pavement and thus calculating the expected pavement life, the data collected at the sites need to be as accurate as possible. Trucks of known weight are used to calibrate the system under any of the COST323 specified test plans (a minimum of 10 test runs per lane/direction) to achieve the highest possible confidence level and targeted accuracy.

The system, like any other weigh-in-motion system, must be calibrated. Calibration is used to ensure that the static weight estimates produced by the weigh-in-motion (WIM) system are as close as possible to the reference weights of the calibrated vehicle.

Calibration also mitigates the effects of site conditions, such as varying pavement temperature, its conditions and vehicle speed. These factors can affect considerably the calculated axle loads. System accuracy can be increased by defining calibration parameters for different groups of characteristic vehicles (i.e. rigid, articulated, buses etc.), but as this is an expensive exercise, a "typical" vehicle (common type for the site) is selected.

Like with all other WIM sensors, only calibration of the entire measuring site provides a clear indication of the accuracy of the weighing results. In the scope of the calibration procedure, the axle loads of reference statically weighed vehicles are compared to weighing results from multiple passes of the same vehicles over the system. Trucks of known weight are used for this purpose, according to one of the test plans set out in the European WIM specification (COST323). The test procedure is selected based on the target accuracy and confidence in the results. The higher the demands, the more elaborate, time consuming and expensive test plan is needed. For simpler calibrations, recommended for periodical checks or short-term installations with accuracy class C(15) or higher, measurements in repeatability conditions (with 1 calibration vehicle only) are sufficient. If possible, the minimum number of calibration runs should be more than 10, as specified in the COST323 specifications, especially if influence of vehicle speed on accuracy is observed.

In the first instance, the selected calibration vehicle is statically weighed, on a calibrated platform scale. As the diagram below shows, this method is not 100% accurate and produces variances throughout the vehicle, the reliable information is the GVW. Only by weighing the vehicle with a complete set of individual static scales, raising the vehicle completely off the ground, would the confidence level of the vehicle be guaranteed for all axles. However, by experience, we have found this method to be satisfactory, and after calibration and the input of the dynamic test results, very accurate.


*Figure 12.* *Calibration vehicle as used at Kaarina 2016.*

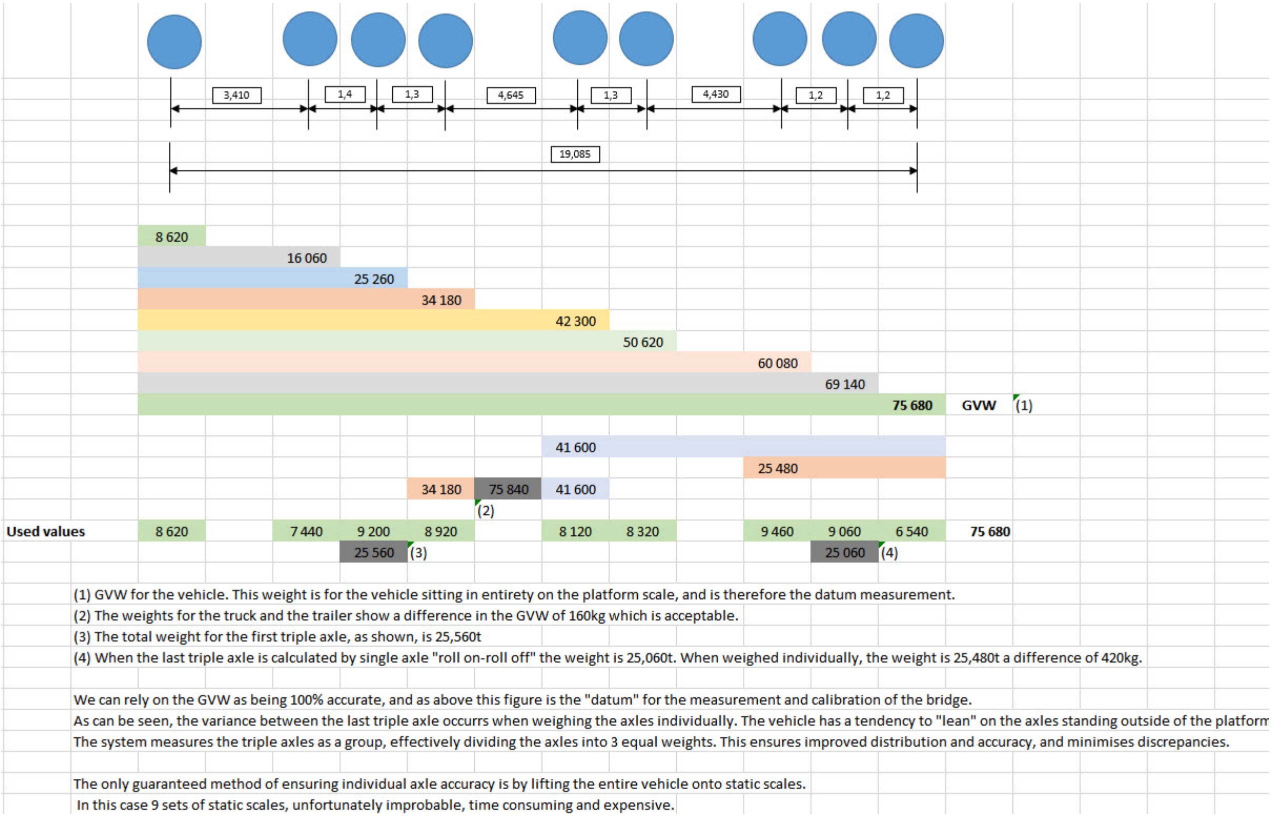



*Figure 13. Static weighing process and results of the calibration vehicle used at Kaarina 2016.*

### Calibration and Test Runs

As above, if possible, the minimum number of calibration runs should be more than 10, as specified in the COST323 specifications, and the initial calibration should take place as soon as possible after installation. It must be noted that on initiation of the system, all data collected is useable, and data collected prior to calibration will be re-processed correctly and included in the results.

The purpose of the calibration is to ensure the accuracy of the system and this is achieved by entering the known references of the vehicle into the "calibration table" located in the SiWIM-F programme. In the first instance, the axle distances are calculated both in the calibration table and by an excel calculation spreadsheet. As with all dynamic testing, results do vary, so the averaging of the (minimum) 10 runs are used to adjust parameters within the system. Once a satisfactory result is achieved, the calibration runs are re-entered into the calibration table, and by calculation the system sets a "calibration factor" which effectively zeros the averages of the runs with the measured values. As this is an average value, there will again be variances in the individual results achieved per vehicle run. The system can then generate an accuracy report as shown below, and this method and report is used for both lanes.

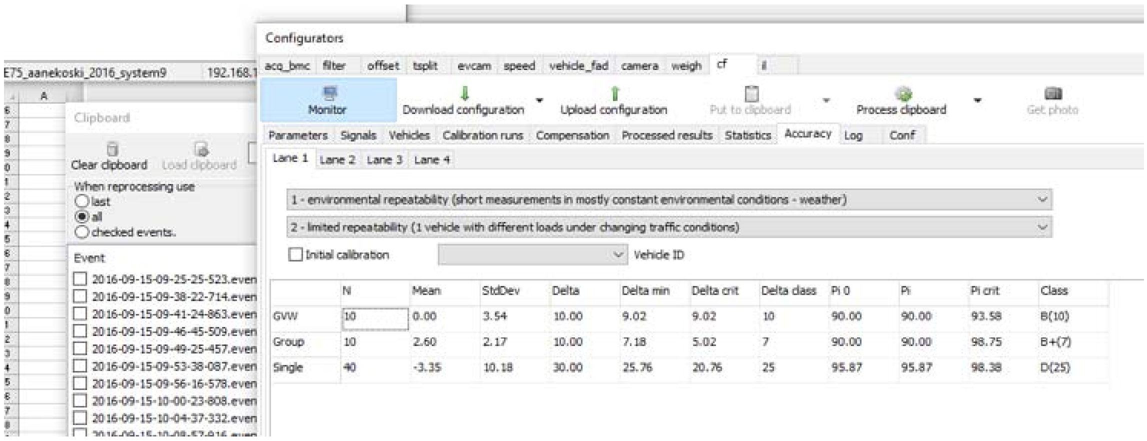



*Figure 14.* *Äänekoski 2016 initial calibration accuracy results from Lane 1.*

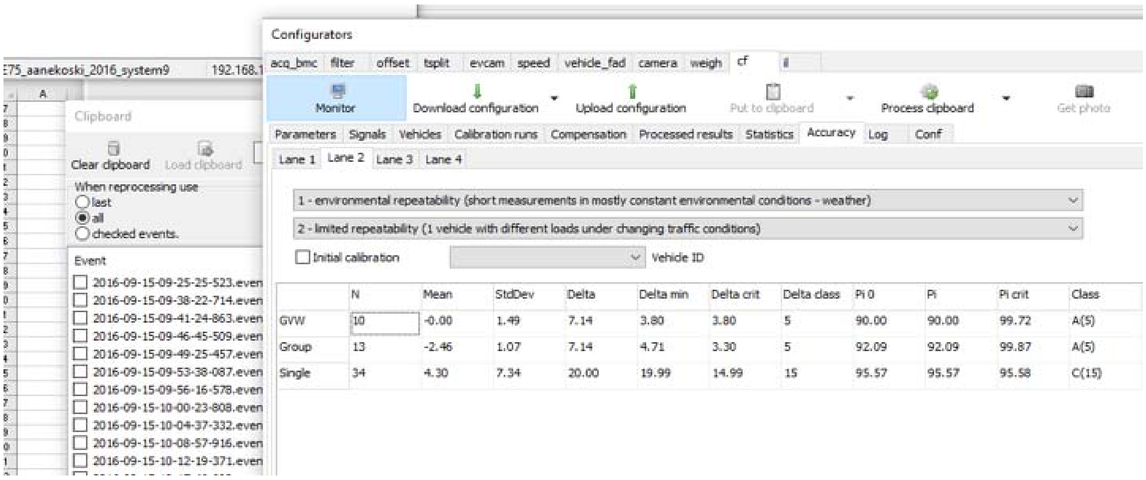



*Figure 15.* *Äänekoski 2016 initial calibration accuracy results from Lane 2.*

When the test period is completed, a test calibration is performed. This requirement is to ensure that the system is stable and to calculate anomalies from the initial calibration (drift), especially on temperature dependent bridges. This drift (although normally small) is calculated as a percentage and is applied to the post-processed results on a pro-rata (equally divided over the measurement period) basis to establish a linear result over the test period.

Calibration test runs are showing a drift of +0,12% for lane 1 and +0,19 % for lane 2 (Figures 16 and 17).

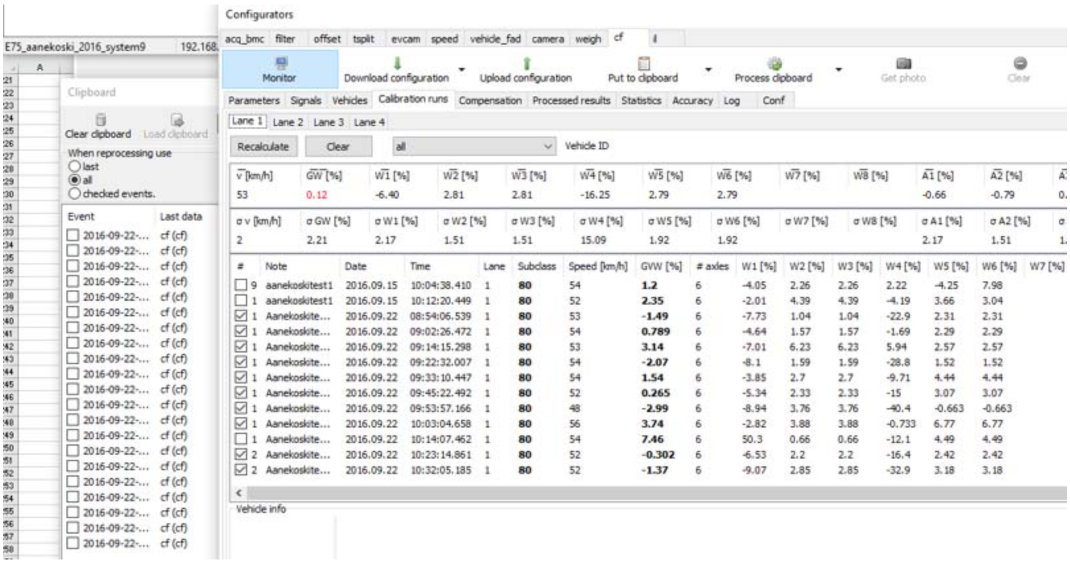


Figure 16. Calibration test runs showing a drift of +0,12% - lane 1.

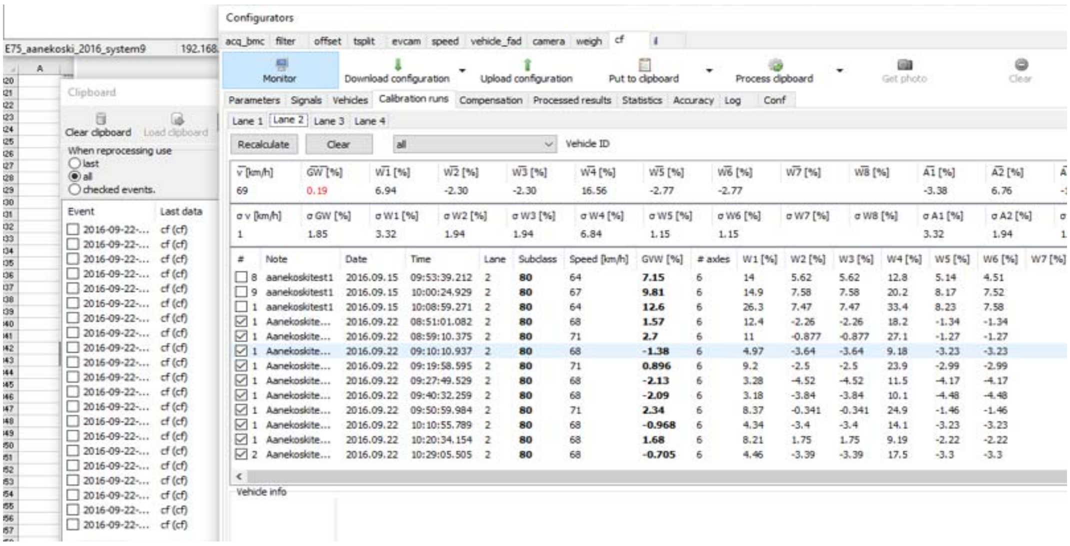


*Figure 17. Calibration test runs showing a drift of +0,19% - lane 2.*

**Comparison between static and dynamic measurements**

Dynamic values measured with weigh in motion systems can vary from static values because of dynamic influence such as bouncing of the vehicle, air resistance and breaking or accelerating of vehicles. All moving vehicles bounce on their tyres and suspensions. There are two main components of this motion: a) low frequency vertical bouncing of the sprung masses, typically at 2 to 4 Hz; and b) high frequency bouncing of the axles (wheel hop), typically at 10 to 15 Hz.

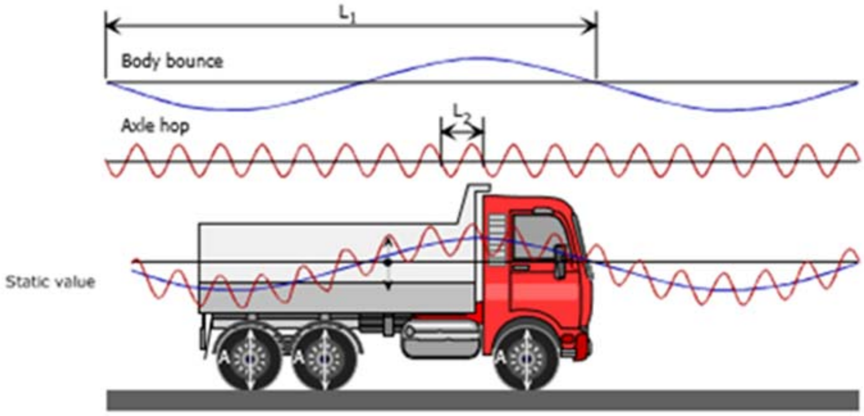



*Figure 18. Dynamics of a driving vehicle: body bounce and axle hop.*

The magnitude of the bounce depends on the roughness of the road, the type of suspension and the vehicle's speed. The SiWIM system has an inbuilt compensation factor to alleviate bounce, where high dynamics in the first axle are spread throughout the remaining axles of the vehicle.

# 2.4 Post processing

All results in this report are processed results, using the SiWIM-D post processing software, during a measured period of 7 complete days, with vehicle weights starting at +10 tons and upwards. Also, the new Finnish vehicle classification table which contains additional Finnish vehicles and special transport vehicles, are used.

The SiWIM-D (SiWIM® Data Processing) was developed to facilitate WIM data evaluation and to process and evaluate results for different application, such as traffic management, pavement design and maintenance (reconstruction) and bridge design and assessment. Its functions include: generation and adjustment of classification tables, fine-tuning of axle loads and spacings and optimization of results based on measured strain signals.

SiWIM-D displays results in different formats, with full details of each individual vehicle, together with the photo, if available.

Classification module identifies, generates, adjusts or removes individual vehicle subclasses defined by axle spacing. It also specifies gross vehicle load limits for vehicle subclasses, which are used in calculation of overloading. The system records individual vehicle data including gross vehicle weight (GVW), axle loads (AL) and spacing, axle group loads, GVW and AL overloading, vehicle class and category, length (wheel base from the front to the rearmost axle), velocity, date and time of passage, temperature, etc.

NSWD files are post-processed with the SiWIM-D software package, which among others:

- searches for doubtful results
- reclassifies vehicles, if necessary
- counts single, double, triple and other axles
- calculates ESAL values for single, double and triple axles

- adds the ESAL value of the vehicle into the SWD file
- calculates overloading for single, double and triple axles
- calculates histograms of single, double and triple axles
- calculates histograms of gross vehicle weights based on vehicle category
- calculates time histograms based on vehicle category
- simulates expected maximum load effects on short span bridges, etc.

Results are presented in metric units.

The system classifies vehicles primarily based on axle spacing. There are no limits for number of classes which can be used. For some specific types of vehicles with similar axle spacing, such as 2-axle trucks and vans, their class is fine-tuned based on the gross vehicle weights and axle loads. For practical purposes vehicle classes are merged into categories.

Comparison of the results of WIM measurements and values obtained through Automatic Traffic Counters (ATC) reveals several significant differences. While WIM systems classify vehicles on the basis of vehicle wheelbases and axle loads, vehicle counter classification is less precise. Similar although smaller differences occur in the distribution of the medium-heavy and heavy vehicles without trailers. ATC uses pre-defined ESAL factors for each specific vehicle type, while the WIM system calculation of ESAL value for each vehicle is based on real axle loads of the particular vehicle.

TSR (Technical Specifications for Roads) specifies ESAL factors per vehicle type and per road type as follows (Table 3):

*Table 3. TSR specification of ESAL factors per vehicle type and per road type.*

| Type of vehicle | ESAL factor for highways | ESAL factor for main roads | ESAL factor for rural roads |
|---|---|---|---|
| BUS | 1,40 | 1,15 | 0,85 |
| Light truck | 0,005 | 0,005 | 0,005 |
| Medium truck | 0,35/0,60 | 0,25/0,50 | 0,25/0,40 |
| Heavy truck | 1,70/0,70 | 1,45/0,90 | 1,35/1,0 |
| Trailer | 1,60 | 1,40 | 1,25 |

TSR specifies ESAL factors per vehicle type and per road type as follows:

$$ESAL = \sum_{i=1}^{n} 10^{-4} \times f_t \times f_a \times P_i^{\alpha}$$

Where

ESAL traffic loading expressed as the sum of nominal (equivalent single) axle loads
$f_a$ axle factor which depends on the type of the axle and the reference axle load
$f_t$ type of the tyre and type of suspension on the axis; factor $f_t$ is often disregarded
P axle loading in tons
$\alpha$ type of the pavement and the damage phenomena; in most countries, a constant value of 4 is used
n number of axles

The ESAL calculations, comparisons and significance, are detailed comprehensively later in this document.

## 2.5 Development for the Finnish traffic conditions, vehicle classifications

The measures completed at Tesjoki and Olhava in 2013 were undertaken prior to the inception of the new regulations in October 2013 under FINLEX regulation 407/2013, clauses 20§ to 30§, all subsequent measurements were after the new regulations were applied. As there were significant changes to the traffic regulations, the probability of new or unexpected vehicles was relatively high (summated in a vehicle class 140 "any other or out of class vehicles") a new vehicle class table was produced to encompass these potential new vehicles, as shown below. The changes in the vehicle configurations was not immediate, but has become more significant as haulers have introduced vehicles to the road network over the ensuing years. We will evaluate these changes later in this document. Full documentation of vehicle class table can be found on separate Excel document: New vehicle classes FI_BWIM.xlsx

*Table 4a.*

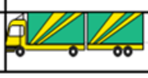
| CAT | CLA | AX | Scheme | | LE | A1 | A2 | A3 | A4 | A5 | A6 | A7 | | GVW-kN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 10 | 2 |  | Min | 0,90 | 0,90 | | | | | | | | 9,81 |
| | | | | Max | 2,00 | 2,00 | | | | | | | | |
| 0 | 20 | 2 |  | Min | 2,00 | 2,00 | | | | | | | | 34,34 |
| | | | | Max | 2,80 | 2,80 | | | | | | | | |
| 0 | 21 | 3 |  | Min | 4,40 | 2,00 | 2,40 | | | | | | | 34,34 |
| | | | | Max | 9,80 | 2,80 | 7,00 | | | | | | | |
| 0 | 22 | 4 |  | Min | 5,30 | 2,00 | 2,40 | 0,90 | | | | | | 34,34 |
| | | | | Max | 11,10 | 2,80 | 7,00 | 1,25 | | | | | | |
| 0 | 30 | 2 |  | Min | 2,80 | 2,80 | | | | | | | | 34,34 |
| | | | | Max | 3,10 | 3,10 | | | | | | | | |
| 0 | 31 | 3 |  | Min | 5,20 | 2,80 | 2,40 | | | | | | | 49,05 |
| | | | | Max | 10,10 | 3,10 | 7,00 | | | | | | | |
| 0 | 32 | 4 |  | Min | 6,10 | 2,80 | 2,40 | 0,90 | | | | | | 49,05 |
| | | | | Max | 11,35 | 3,10 | 7,00 | 1,25 | | | | | | |
| 1 | 40 | 2 |  | Min | 3,10 | 3,10 | | | | | | | | 176,58 |
| | | | | Max | 5,30 | 5,30 | | | | | | | | |
| 1 | 42 | 2 |  | Min | 1,40 | 1,40 | | | | | | | | 176,58 |
| | | | | Max | 2,00 | 2,00 | | | | | | | | |
| 3 | 43 | 9 |  | Min | 6,40 | 2,20 | 1,25 | 2,00 | 0,90 | 3,60 | 0,90 | 0,90 | 0,90 | 745,56 |
| | | | | Max | 17,20 | 7,00 | 2,40 | 6,00 | 1,75 | 6,20 | 2,00 | 2,00 | 2,00 | |
| 8 | 44 | 14 | | Min | 18,08 | 1,60 | 1,30 | 1,30 | 2,00 | 1,32 | 1,32 | 1,32 | 1,32 | 1,32 |
| | | | | Max | 26,70 | 3,50 | 2,20 | 1,80 | 3,00 | 1,80 | 1,80 | 1,80 | 1,80 | 1,80 |
| 8 | 45 | 15 | | Min | 20,28 | 1,60 | 1,30 | 1,30 | 2,00 | 1,32 | 1,32 | 2,20 | 1,32 | 1,32 |
| | | | | Max | 29,80 | 3,00 | 2,20 | 1,80 | 3,30 | 1,80 | 1,80 | 3,30 | 1,80 | 1,80 |
| 8 | 46 | 16 | | Min | 20,62 | 1,60 | 1,25 | 1,25 | 2,00 | 1,32 | 1,32 | 1,32 | 1,32 | 1,32 |
| | | | | Max | 30,10 | 3,00 | 2,20 | 1,80 | 3,30 | 1,80 | 1,80 | 1,80 | 1,80 | 1,80 |
| 2 | 50 | 3 |  | Min | 3,10 | 2,20 | 0,90 | | | | | | | 245,25 |
| | | | | Max | 5,30 | 4,00 | 1,25 | | | | | | | |
| 2 | 51 | 3 |  | Min | 3,50 | 2,20 | 1,25 | | | | | | | 245,25 |
| | | | | Max | 5,80 | 4,00 | 1,75 | | | | | | | |
| 2 | 52 | 3 |  | Min | 4,00 | 2,20 | 1,75 | | | | | | | 255,06 |
| | | | | Max | 6,40 | 4,00 | 2,40 | | | | | | | |
| 2 | 53 | 3 |  | Min | 4,90 | 4,00 | 0,90 | | | | | | | 245,25 |
| | | | | Max | 6,60 | 5,30 | 1,25 | | | | | | | |
| 2 | 54 | 3 |  | Min | 5,30 | 4,00 | 1,25 | | | | | | | 245,25 |
| | | | | Max | 7,10 | 5,30 | 1,75 | | | | | | | |
| 2 | 55 | 3 |  | Min | 5,80 | 4,00 | 1,75 | | | | | | | 255,06 |
| | | | | Max | 7,70 | 5,30 | 2,40 | | | | | | | |
| 2 | 57 | 4 |  | Min | 2,70 | 0,90 | 0,90 | 0,90 | | | | | | 353,16 |
| | | | | Max | 10,60 | 2,20 | 6,00 | 2,40 | | | | | | |
| 2 | 58 | 4 |  | Min | 3,90 | 2,10 | 0,90 | 0,90 | | | | | | 353,16 |
| | | | | Max | 10,80 | 6,00 | 2,40 | 2,40 | | | | | | |
| 3 | 60 | 3 |  | Min | 6,40 | 4,00 | 2,40 | | | | | | | 274,68 |
| | | | | Max | 15,30 | 5,30 | 10,00 | | | | | | | |
| 3 | 61 | 4 |  | Min | 9,90 | 3,00 | 6,00 | 0,90 | | | | | | 353,16 |
| | | | | Max | 20,40 | 8,00 | 10,00 | 2,40 | | | | | | |

*Table 4b.*

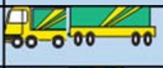
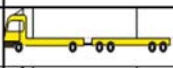
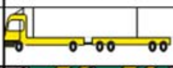
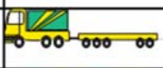
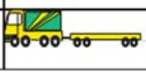
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 62 | 4 |  | Min | 6,80 | 2,00 | 2,40 | 2,40 | | | | | | 353,16 |
| | | | | Max | 26,00 | 8,00 | 9,00 | 9,00 | | | | | | |
| 3 | 63 | 3 |  | Min | 3,80 | 1,40 | 2,40 | | | | | | | 274,68 |
| | | | | Max | 12,00 | 2,00 | 10,00 | | | | | | | |
| 3 | 64 | 4 |  | Min | 4,70 | 1,40 | 2,40 | 0,90 | | | | | | 353,16 |
| | | | | Max | 22,00 | 2,00 | 10,00 | 10,00 | | | | | | |
| 3 | 65 | 4 |  | Min | 4,50 | 1,20 | 2,40 | 0,90 | | | | | | 353,16 |
| | | | | Max | 16,50 | 3,50 | 10,00 | 3,00 | | | | | | |
| 3 | 66 | 6 |  | Min | 7,70 | 0,90 | 2,50 | 0,90 | 2,50 | 0,90 | | | | 519,93 |
| | | | | Max | 20,60 | 2,20 | 6,00 | 2,20 | 8,00 | 2,20 | | | | |
| 3 | 67 | 6 |  | Min | 12,40 | 0,90 | 2,80 | 3,90 | 3,90 | 0,90 | | | | 519,93 |
| | | | | Max | 23,40 | 2,20 | 5,00 | 7,00 | 7,00 | 2,20 | | | | |
| 3 | 68 | 7 |  | Min | 13,30 | 0,90 | 2,80 | 3,90 | 0,90 | 3,90 | 0,90 | | | **588,6** |
| | | | | Max | 25,60 | 2,20 | 5,00 | 7,00 | 2,20 | 7,00 | 2,20 | | | |
| 3 | 69 | 5 |  | Min | 10,30 | 0,90 | 2,20 | 5,00 | 2,20 | | | | | 431,64 |
| | | | | Max | 25,40 | 3,20 | 5,20 | 10,00 | 7,00 | | | | | |
| 3 | 70 | 5 |  | Min | 7,90 | 2,20 | 2,40 | 2,40 | 0,90 | | | | | 431,64 |
| | | | | Max | 26,80 | 6,50 | 10,00 | 9,00 | 1,25 | | | | | |
| 3 | 71 | 5 |  | Min | 8,30 | 2,20 | 2,40 | 2,40 | 1,25 | | | | | 431,64 |
| | | | | Max | 27,30 | 6,50 | 10,00 | 9,00 | 1,75 | | | | | |
| 3 | 72 | 5 |  | Min | 8,80 | 2,20 | 2,40 | 2,40 | 1,75 | | | | | 431,64 |
| | | | | Max | 27,90 | 6,50 | 10,00 | 9,00 | 2,40 | | | | | |
| 3 | 73 | 5 |  | Min | 6,90 | 1,80 | 2,40 | 0,90 | 1,75 | | | | | 431,64 |
| | | | | Max | 28,30 | 6,50 | 10,00 | 1,75 | 10,00 | | | | | |
| 3 | 74 | 5 |  | Min | 10,10 | 2,30 | 6,00 | 0,90 | 0,90 | | | | | 431,64 |
| | | | | Max | 24,20 | 6,50 | 10,00 | 3,50 | 4,20 | | | | | |
| 3 | 75 | 6 |  | Min | 8,25 | 1,75 | 2,40 | 0,90 | 2,40 | 0,90 | | | | 519,93 |
| | | | | Max | 31,25 | 6,50 | 8,00 | 2,40 | 11,00 | 3,25 | | | | |
| 3 | 76 | 6 |  | Min | 9,70 | 2,20 | 2,40 | 0,90 | 2,40 | 1,75 | | | | 519,93 |
| | | | | Max | 30,30 | 6,50 | 8,00 | 2,40 | 11,00 | 2,40 | | | | |
| 3 | 77 | 6 |  | Min | 8,80 | 2,20 | 2,40 | 2,40 | 0,90 | 0,90 | | | | 519,93 |
| | | | | Max | 25,30 | 6,50 | 8,00 | 6,00 | 2,40 | 2,40 | | | | |
| 3 | 78 | 7 |  | Min | 9,70 | 2,20 | 2,40 | 0,90 | 2,40 | 0,90 | 0,90 | | | 588,60 |
| | | | | Max | 29,70 | 6,50 | 8,00 | 2,40 | 8,00 | 2,40 | 2,40 | | | |
| 3 | 79 | 7 |  | Min | 9,70 | 2,20 | 2,40 | 0,90 | 0,90 | 2,40 | 0,90 | | | 588,60 |
| | | | | Max | 29,70 | 6,50 | 8,00 | 2,40 | 2,40 | 8,00 | 2,40 | | | |
| 3 | 80 | 4 |  | Min | 6,60 | 3,30 | 0,90 | 2,40 | | | | | | 353,16 |
| | | | | Max | 19,40 | 7,00 | 2,40 | 10,00 | | | | | | |
| 3 | 81 | 5 |  | Min | 10,00 | 2,20 | 0,90 | 6,00 | 0,90 | | | | | 431,64 |
| | | | | Max | 20,50 | 7,00 | 1,75 | 10,00 | 1,75 | | | | | |
| 3 | 82 | 5 |  | Min | 10,90 | 2,20 | 0,90 | 6,00 | 1,75 | | | | | 431,64 |
| | | | | Max | 21,20 | 7,00 | 1,75 | 10,00 | 2,40 | | | | | |
| 3 | 83 | 5 |  | Min | 7,50 | 2,20 | 0,90 | 2,00 | 2,40 | | | | | 431,64 |
| | | | | Max | 29,20 | 7,00 | 3,20 | 10,00 | 9,00 | | | | | |
| 3 | 84 | 6 |  | Min | 11,60 | 2,50 | 1,25 | 6,00 | 0,90 | 0,90 | | | | 519,93 |
| | | | | Max | 22,90 | 7,00 | 2,40 | 10,00 | 1,75 | 1,75 | | | | |
| 3 | 85 | 8 |  | Min | 14,40 | 0,90 | 2,20 | 0,90 | 3,60 | 0,90 | 5,00 | 0,90 | | 588,60 |
| | | | | Max | 33,40 | 2,20 | 6,00 | 2,40 | 9,00 | 2,40 | 9,00 | 2,40 | | |

*Table 4c.*

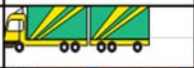
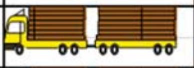
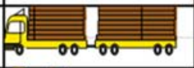
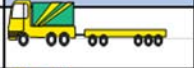
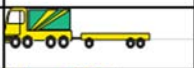
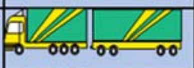
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 86 | 7 |  | Min | 18,90 | 2,20 | 2,40 | 0,90 | 6,00 | 5,00 | 0,90 | | | 588,60 |
| | | | | Max | 37,60 | 6,50 | 8,00 | 2,20 | 10,00 | 9,00 | 2,40 | | | |
| 3 | 87 | 5 |  | Min | 7,00 | 2,40 | 0,90 | 0,90 | 2,80 | | | | | 431,64 |
| | | | | Max | 17,60 | 6,00 | 2,20 | 2,20 | 7,20 | | | | | |
| 3 | 88 | 8 |  | Min | 14,20 | 0,90 | 2,80 | 0,90 | 3,90 | 0,90 | 3,90 | 0,90 | | **667,1** |
| | | | | Max | 27,80 | 2,20 | 5,00 | 2,20 | 7,00 | 2,20 | 7,00 | 2,20 | | |
| 3 | 89 | 6 |  | Min | 9,30 | 2,50 | 0,90 | 0,90 | 2,50 | 2,50 | | | | 519,93 |
| | | | | Max | 23,90 | 5,50 | 2,20 | 2,20 | 7,00 | 7,00 | | | | |
| 3 | 90 | 6 |  | Min | 10,30 | 2,20 | 0,90 | 2,40 | 2,40 | 2,40 | | | | 519,93 |
| | | | | Max | 28,70 | 7,00 | 2,40 | 8,30 | 6,00 | 6,00 | | | | |
| 3 | 91 | 6 |  | Min | 8,80 | 2,20 | 0,90 | 2,40 | 2,40 | 0,90 | | | | 519,93 |
| | | | | Max | 29,80 | 7,00 | 2,40 | 8,00 | 10,00 | 2,40 | | | | |
| 3 | 92 | 6 |  | Min | 8,20 | 2,20 | 0,90 | 2,40 | 0,90 | 1,75 | | | | 519,93 |
| | | | | Max | 30,80 | 7,00 | 2,40 | 9,00 | 2,40 | 10,00 | | | | |
| 3 | 93 | 7 |  | Min | 9,10 | 2,20 | 0,90 | 2,40 | 0,90 | 1,75 | 0,90 | | | 588,60 |
| | | | | Max | 33,60 | 7,00 | 2,40 | 9,00 | 2,40 | 11,00 | 1,75 | | | |
| 3 | 94 | 7 |  | Min | 9,90 | 2,20 | 0,90 | 2,40 | 0,90 | 1,75 | 1,75 | | | 588,60 |
| | | | | Max | 34,20 | 7,00 | 2,40 | 9,00 | 2,40 | 11,00 | 2,40 | | | |
| 3 | 95 | 7 |  | Min | 9,70 | 2,20 | 0,90 | 2,40 | 2,40 | 0,90 | 0,90 | | | 588,60 |
| | | | | Max | 30,10 | 7,00 | 2,40 | 9,00 | 8,00 | 2,40 | 1,25 | | | |
| 3 | 96 | 7 |  | Min | 7,70 | 1,00 | 0,90 | 2,40 | 1.6 | 0,90 | 0,90 | | | 588,60 |
| | | | | Max | 31,20 | 7,00 | 2,40 | 9,00 | 8,00 | 2,40 | 2,40 | | | |
| 3 | 97 | 8 |  | Min | 10,60 | 2,20 | 0,90 | 2,40 | 0,90 | 2,40 | 0,90 | 0,90 | | 667,08 |
| | | | | Max | 33,60 | 7,00 | 2,40 | 9,00 | 2,40 | 8,00 | 2,40 | 2,40 | | |
| 3 | 98 | 8 |  | Min | 10,60 | 2,20 | 0,90 | 2,40 | 0,90 | 2,40 | 0,90 | 0,90 | | 667,08 |
| | | | | Max | 33,60 | 7,00 | 2,40 | 9,00 | 2,40 | 8,00 | 2,40 | 2,40 | | |
| 4 | 99 | 7 |  | Min | 10,70 | 0,90 | 2,00 | 0,90 | 3,60 | 2,40 | 0,90 | | | 588,60 |
| | | | | Max | 27,40 | 2,40 | 4,20 | 2,40 | 8,00 | 8,00 | 2,40 | | | |
| 4 | 100 | 3 |  | Min | 5,00 | 2,60 | 2,40 | | | | | | | 392,40 |
| | | | | Max | 15,30 | 5,30 | 10,00 | | | | | | | |
| 4 | 101 | 4 |  | Min | 5,50 | 2,60 | 2,00 | 0,90 | | | | | | 353,16 |
| | | | | Max | 14,30 | 7,00 | 6,00 | 1,75 | | | | | | |
| 4 | 102 | 4 |  | Min | 5,50 | 2,20 | 2,00 | 0,90 | | | | | | 353,16 |
| | | | | Max | 14,80 | 7,00 | 6,00 | 1,75 | | | | | | |
| 4 | 103 | 4 |  | Min | 6,00 | 2,20 | 2,00 | 1,25 | | | | | | 353,16 |
| | | | | Max | 15,40 | 7,00 | 6,00 | 2,40 | | | | | | |
| 4 | 104 | 4 |  | Min | 4,50 | 1,20 | 2,40 | 0,90 | | | | | | 353,16 |
| | | | | Max | 16,50 | 3,50 | 10,00 | 3,00 | | | | | | |
| 3 | 105 | 7 |  | Min | 10,60 | 2,90 | 0,90 | 0,90 | 2,60 | 2,40 | 0,90 | | | 588,60 |
| | | | | Max | 23,20 | 4,40 | 2,20 | 2,20 | 6,00 | 6,00 | 2,40 | | | |
| 3 | 106 | 8 |  | Min | 13,70 | 2,90 | 0,90 | 0,90 | 3,20 | 0,90 | 4,00 | 0,90 | | 667,08 |
| | | | | Max | 29,70 | 5,50 | 2,00 | 2,40 | 6,00 | 2,40 | 9,00 | 2,40 | | |
| 4 | 107 | 7 |  | Min | 8,20 | 2,20 | 0,90 | 0,90 | 2,40 | 0,90 | 0,90 | | | 588,60 |
| | | | | Max | 20,40 | 5,00 | 2,20 | 2,20 | 7,00 | 2,00 | 2,00 | | | |
| 3 | 108 | 6 |  | Min | 7,30 | 2,20 | 0,90 | 0,90 | 2,40 | 0,90 | | | | 519,93 |
| | | | | Max | 20,30 | 6,00 | 2,20 | 2,20 | 7,50 | 2,40 | | | | |
| 3 | 109 | 7 |  | Min | 12,70 | 2,90 | 0,90 | 0,90 | 2,60 | 0,90 | 4,50 | | | 588,60 |
| | | | | Max | 25,60 | 4,80 | 2,20 | 2,20 | 6,00 | 2,40 | 8,00 | | | |

*Table 4d.*

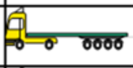
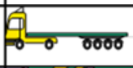
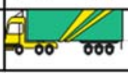
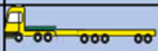
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 110 | 5 |  | Min | 6,00 | 2,20 | 2,00 | 0,90 | 0,90 | | | | | 431,64 |
| | | | | Max | 13,50 | 5,00 | 6,00 | 1,25 | 1,25 | | | | | |
| 4 | 111 | 5 |  | Min | 6,40 | 2,20 | 2,00 | 0,90 | 1,25 | | | | | 431,64 |
| | | | | Max | 14,00 | 5,00 | 6,00 | 1,25 | 1,75 | | | | | |
| 4 | 112 | 5 |  | Min | 6,90 | 2,20 | 2,00 | 0,90 | 1,75 | | | | | 431,64 |
| | | | | Max | 14,70 | 5,00 | 6,00 | 1,25 | 2,40 | | | | | |
| 4 | 113 | 5 |  | Min | 6,40 | 2,20 | 2,00 | 1,25 | 0,90 | | | | | 431,64 |
| | | | | Max | 17,20 | 5,00 | 8,00 | 2,40 | 1,75 | | | | | |
| 4 | 114 | 5 |  | Min | 7,20 | 2,20 | 2,00 | 1,25 | 1,75 | | | | | 431,64 |
| | | | | Max | 19,80 | 5,00 | 10,00 | 2,40 | 2,40 | | | | | |
| 4 | 115 | 6 |  | Min | 7,95 | 2,20 | 2,00 | 1,25 | 1,25 | 1,25 | | | | 519,93 |
| | | | | Max | 18,20 | 5,00 | 6,00 | 2,40 | 2,40 | 2,40 | | | | |
| 4 | 116 | 6 |  | Min | 7,50 | 2,20 | 2,00 | 1,10 | 1,10 | 1,10 | | | | 519,93 |
| | | | | Max | 25,80 | 5,00 | 10,00 | 3,60 | 3,60 | 3,60 | | | | |
| 3 | 117 | 7 |  | Min | 14,30 | 2,85 | 0,90 | 0,90 | 2,60 | 6,10 | 0,90 | | | 667,08 |
| | | | | Max | 27,20 | 4,40 | 2,20 | 2,20 | 6,00 | 10,00 | 2,40 | | | |
| 3 | 118 | 7 |  | Min | 12,00 | 0,90 | 2,00 | 0,90 | 2,80 | 0,90 | 4,50 | | | 588,60 |
| | | | | Max | 28,20 | 2,40 | 4,50 | 2,40 | 8,00 | 2,40 | 8,50 | | | |
| 3 | 119 | 7 |  | Min | 8,40 | 0,90 | 2,00 | 0,90 | 2,80 | 0,90 | 0,90 | | | 588,60 |
| | | | | Max | 23,10 | 2,40 | 5,50 | 2,40 | 8,00 | 2,40 | 2,40 | | | |
| 4 | 120 | 5 |  | Min | 6,00 | 2,20 | 0,90 | 2,00 | 0,90 | | | | | 431,64 |
| | | | | Max | 16,00 | 7,00 | 1,25 | 6,00 | 1,75 | | | | | |
| 4 | 121 | 5 |  | Min | 6,90 | 2,20 | 0,90 | 2,00 | 1,25 | | | | | 431,64 |
| | | | | Max | 16,70 | 7,00 | 1,25 | 6,00 | 2,40 | | | | | |
| 4 | 122 | 5 |  | Min | 6,40 | 2,20 | 1,25 | 1,25 | 0,90 | | | | | 431,64 |
| | | | | Max | 17,20 | 7,00 | 2,40 | 6,00 | 1,75 | | | | | |
| 4 | 123 | 5 |  | Min | 7,20 | 2,20 | 1,25 | 2,00 | 1,75 | | | | | 431,64 |
| | | | | Max | 18,40 | 7,00 | 2,40 | 6,00 | 3,00 | | | | | |
| 4 | 124 | 4 |  | Min | 5,10 | 2,20 | 0,90 | 2,00 | | | | | | 353,16 |
| | | | | Max | 13,70 | 3,30 | 2,40 | 8,00 | | | | | | |
| 4 | 125 | 6 |  | Min | 9,50 | 0,90 | 2,00 | 0,90 | 2,20 | 3,50 | | | | 519,93 |
| | | | | Max | 24,30 | 2,60 | 6,00 | 2,20 | 6,50 | 7,00 | | | | |
| 3 | 126 | 9 |  | Min | 14,30 | 2,60 | 0,90 | 3,60 | 0,90 | 0,90 | 3,60 | 0,90 | 0,90 | **745,6** |
| | | | | Max | 29,90 | 5,10 | 2,00 | 6,50 | 1,90 | 1,90 | 8,90 | 1,80 | 1,80 | |
| 3 | 127 | 9 |  | Min | 13,40 | 2,60 | 0,90 | 0,90 | 3,20 | 0,90 | 3,10 | 0,90 | 0,90 | **745,6** |
| | | | | Max | 30,10 | 5,20 | 2,00 | 2,00 | 6,50 | 1,90 | 8,90 | 1,80 | 1,80 | |
| 3 | 128 | 9 |  | Min | 11,40 | 0,90 | 2,10 | 0,90 | 2,10 | 0,90 | 2,70 | 0,90 | 0,90 | **745,6** |
| | | | | Max | 30,00 | 2,10 | 5,50 | 2,00 | 6,00 | 1,90 | 8,90 | 1,80 | 1,80 | |
| 3 | 129 | 8 |  | Min | 14,40 | 3,30 | 3,90 | 0,90 | 0,90 | 3,60 | 0,90 | 0,90 | | **667,1** |
| | | | | Max | 25,75 | 6,10 | 5,80 | 2,00 | 2,00 | 5,85 | 2,00 | 2,00 | | |
| 4 | 130 | 6 |  | Min | 7,30 | 2,20 | 0,90 | 2,40 | 0,90 | 0,90 | | | | 519,93 |
| | | | | Max | 16,90 | 5,00 | 1,25 | 7,00 | 2,40 | 1,75 | | | | |
| 4 | 131 | 6 |  | Min | 7,70 | 2,20 | 0,90 | 2,40 | 0,90 | 1,25 | | | | 519,93 |
| | | | | Max | 16,40 | 4,00 | 1,25 | 7,00 | 2,40 | 1,75 | | | | |
| 4 | 132 | 6 |  | Min | 8,20 | 2,20 | 0,90 | 2,40 | 0,90 | 1,25 | | | | 519,93 |
| | | | | Max | 18,10 | 5,00 | 1,25 | 7,00 | 2,40 | 2,40 | | | | |
| 4 | 133 | 6 |  | Min | 7,70 | 2,20 | 1,25 | 2,40 | 0,90 | 0,90 | | | | 519,93 |
| | | | | Max | 18,10 | 5,00 | 2,40 | 7,00 | 2,40 | 1,75 | | | | |

*Table 4e.*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 134 | 6 |  | Min | 8,00 | 2,20 | 1,25 | 2,40 | 0,90 | 1,25 | | | | 519,93 |
| | | | | Max | 18,60 | 5,00 | 2,40 | 7,00 | 2,40 | 2,40 | | | | |
| 3 | 135 | 8 |  | Min | 10,50 | 0,90 | 2,10 | 0,90 | 2,10 | 2,70 | 0,90 | 0,90 | | 667,1 |
| | | | | Max | 28,10 | 2,10 | 5,50 | 2,00 | 6,00 | 8,90 | 1,80 | 1,80 | | |
| 5 | 136 | 7 |  | Min | 6,50 | 2,00 | 0,90 | 0,90 | 0,90 | 0,90 | 0,90 | | | 588,6 |
| | | | | Max | 42,00 | 5,50 | 2,80 | 9,50 | 9,80 | 8,80 | 5,60 | | | |
| 4 | 137 | 8 |  | Min | 9,10 | 2,20 | 0,90 | 2,40 | 0,90 | 0,90 | 0,90 | 0,90 | | 667,8 |
| | | | | Max | 29,40 | 5,50 | 2,40 | 9,50 | 2,80 | 2,80 | 3,60 | 2,80 | | |
| 4 | 138 | 8 |  | Min | 10,70 | 2,20 | 0,90 | 2,40 | 0,90 | 0,90 | 2,50 | 0,90 | | 667,8 |
| | | | | Max | 32,10 | 5,20 | 2,40 | 9,50 | 2,80 | 2,80 | 6,60 | 2,80 | | |
| 3 | 139 | 7 |  | Min | 8,20 | 2,20 | 0,90 | 2,40 | 0,90 | 0,90 | 0,90 | | | 588,6 |
| | | | | Max | 37,30 | 7,00 | 2,40 | 9,00 | 2,40 | 11,00 | 5,50 | | | |
| 5 | 41 | 2 |  | Min | 5,30 | 5,30 | | | | | | | | 176,58 |
| | | | | Max | 8,00 | 8,00 | | | | | | | | |
| 5 | 56 | 3 |  | Min | 6,20 | 5,30 | 0,90 | | | | | | | 245,25 |
| | | | | Max | 9,80 | 8,00 | 1,75 | | | | | | | |
| 6 | 59 | 3 |  | Min | 7,10 | 5,30 | 1,75 | | | | | | | 392,40 |
| | | | | Max | 18,00 | 8,00 | 10,00 | | | | | | | |
| | 140 | | Non-classified vehicles | | | 0 | | | | | | | | |

*CA – vehicle category; CL- vehicle class, AX – Number of axles; LE – length from first to last axle; A1 to A7 – axle spacings 1 to 7*

*Axle distance unchanged*
*Axle distance reduced*
*Axle distance increased*
*New vehicle class and configuration Sweden*
*New vehicle class and configuration Finland*

# 3 Measured bridges, with overview results per year 2013-2017

All the reports produced after processing with the SiWIM-D programme are extracted from the excel report that is generated. The format of the report, is an agreed representation of the results, and has been used in this form for many years. Each of the sections show e.g., in graphic form:

- Traffic density for: GVW - single - double -triple axles total traffic.
- Average weight distributions over a 24-hour period.
- Vehicle/class analysis.
- Load distributions for: total - 2 axle - 3 axle - trailers - semi trailers and busses.
- Average ESAL values for vehicle classes.
- Overload results for: total - for vehicle types - for axle frequencies.

All results in this report are re-processed results with weights <u>starting at +10 tons and upwards</u>. Also the <u>new Finnish vehicle classification table</u>, which contains recently added Finnish vehicles and special transport vehicles, are used.

This new vehicle classification table also complies with Eurocodes and Finlex regulations.

The official names of the measured bridges with bridge identification codes are presented in the tables about general bridge data.

**Terms** (used in each site report in this chapter 3)

1) Average speed: Sum of all individual speeds divided by the number of vehicles.
2) Total GVW: Total number of vehicles x GVW.
3) Average ESAL value: The sum of all individual ESAL´s divided by the number of vehicles.

| | |
|---|---|
| All: | All vehicles heavier than 10 tons. |
| All 5%: | All vehicles heavier than 10 tons with a filter of 5% over the legal level. |
| +35t: | All vehicles heavier than 35 tons. |
| +35t +5%: | All vehicles heavier than 35 tons with a filter of 5% over the legal level. |

# 3.1 Tesjoki 2013

### 3.1.1 Overview, Main Road VT7 (E18)

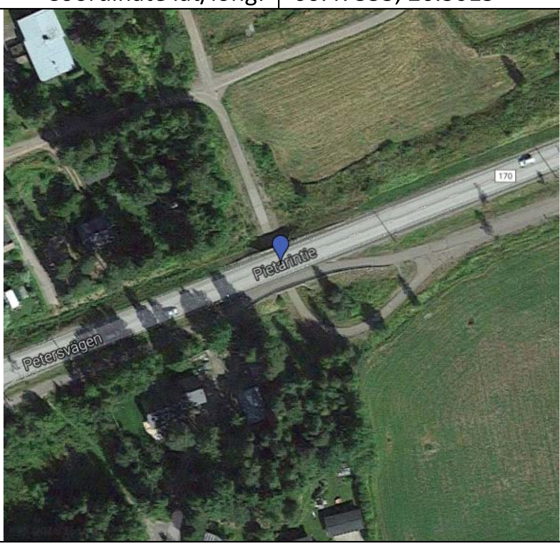
This bridge was within the region where the project 'E18 Koskenkylä – Kokta', a new motorway, was under construction, about 5 km east from Loviisa. The new motorway diverts from the original road section at Loviisa (easterly direction), and was to be completed later in 2013, so there was no adverse effect on traffic flow. There was a possibility that some through traffic may have taken an alternative route, but it was agreed that this traffic was minimal.

The bridge provides pedestrian access under the busy main road, and vehicles are not permitted. Power was provided from carriageway lighting.


*Figure 19. The old (red) and new (blue) road lines for highway 7 (E18) between Loviisa and Kotka.*

*Table 5. Bridge data of Tesjoki bridge.*

| | |
|---|---|
| Bridge name: | Tesjoki (Marakatin alikulkukäytävä) |
| Road/Location: | E18 between Kotka and Lovisa |
| Lanes: | 1+1 |
| Measured direction: | Both |
| Bridge Id: | U-1855 |
| Bridge type: | Slab - simply supported |
| Coordinate lat/long: | 60.47353, 26.3015 |





Source: Google.com

*Table 6. Measured traffic data from Tesjoki bridge measurement 2013.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| Results | ESAL | # Per day | GVW | Weight | Amount | Axle | GVW | Both |
| 2013 | 0,96 | 1 047 | 26,65 t | 195 492 t | 7 335 | 18,9% | 0,1% | 0,8% |

### 3.1.2 Measurement 2013

The instrumentation was installed on 24th September 2013, and initial influence lines showed that this was a well-constructed bridge suitable for WIM measurements.

The influence line in lane 1 easterly towards Kotka was very smooth and lane 2 showed a very small amount of dynamic when leaving the bridge platform.

The first calibration was made on 25th September using a local aggregate vehicle of axle design 1312. As a triple axled truck is not an ideal calibration vehicle, the 2nd axle was raised to produce a 6 axle vehicle of 1212 formation. The first calibration gave results of: GVW B10 and Group axles A5 for both lanes. The second calibration took place on 8th October using a very similar vehicle, and produced results of: Lane 1 - GVW B10 and Group axles B+7, lane 2 – GVW B+7 and Group axles A5.

The variance between the two calibrations (drift) was 0,85% on lane 1, and 0,54% on lane 2. This was an excellent result and shows the bridge and measure had a high degree of stability.

The weather over the period was reasonable with some precipitation. Temperatures were +6°C at the outset and +10°C when the system was dismantled on 8th October.

Measurement results are presented in tables 7 and 8 as accumulative statistics for the vehicle groups on different lanes and in figures 20 and 21 as cumulative load distributions on different lanes.

*Table 7. Accumulative statistics for the vehicle groups lane 1, towards Kotka:*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 188 | 322 | 1 448 | 1 156 | 533 | 5 | **3 652** |
| **Speed (ave.)¹** | 68,62 | 67,96 | 69,26 | 67,99 | 69,07 | 69,62 | **68,69** |
| **GVW average** | 13,38 | 22,14 | 35,49 | 28,44 | 15,62 | 38,48 | **28,05** |
| **Total GVW²** | 2 515,44 | 7 129,08 | 51 389,52 | 32 876,64 | 8 325,46 | 192,40 | **102 438,60** |
| **ESAL (Ave.)³** | 0,77 | 0,8 | 1,24 | 0,87 | 0,91 | 0,75 | **1,01** |

*Table 8. Accumulative statistics for the vehicle groups lane 2, towards Lovisa:*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 263 | 259 | 1 770 | 840 | 547 | 4 | **3 683** |
| **Speed (ave.)¹** | 68,39 | 68,41 | 68,39 | 66,77 | 70,42 | 71,01 | **68,33** |
| **GVW average** | 13,7 | 20,1 | 30,21 | 26,71 | 15,06 | 24,96 | **25,27** |
| **Total GVW²** | 3 603,10 | 5 205,90 | 53 471,70 | 22 436,40 | 8 237,82 | 99,84 | **93 069,41** |
| **ESAL (Ave.)³** | 0,87 | 0,65 | 1,01 | 0,87 | 0,84 | 0,56 | **0,91** |

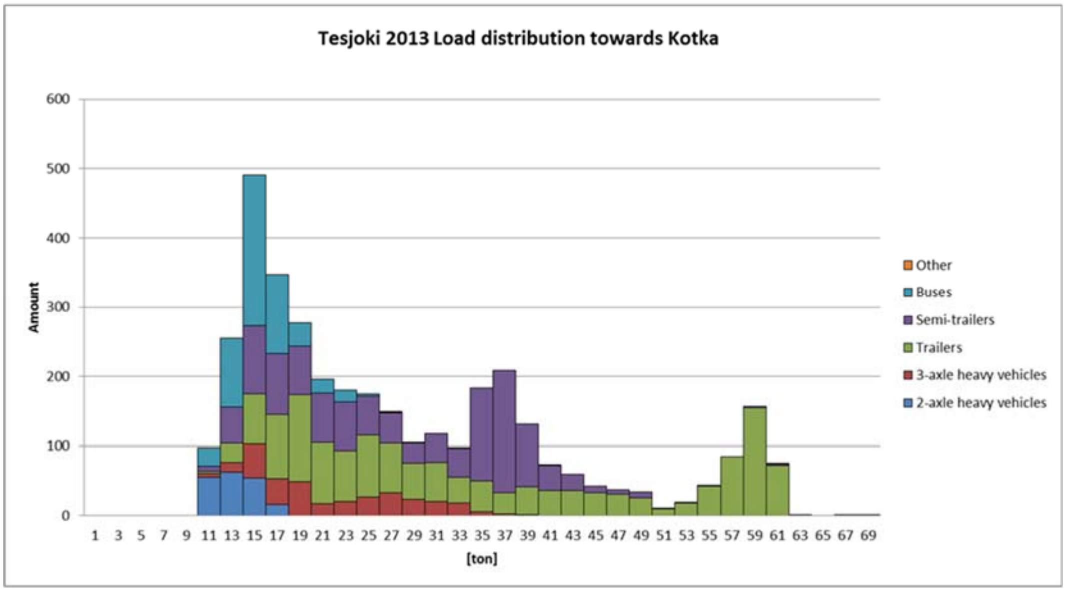



*Figure 20. Load distribution cumulative, towards Kotka.*

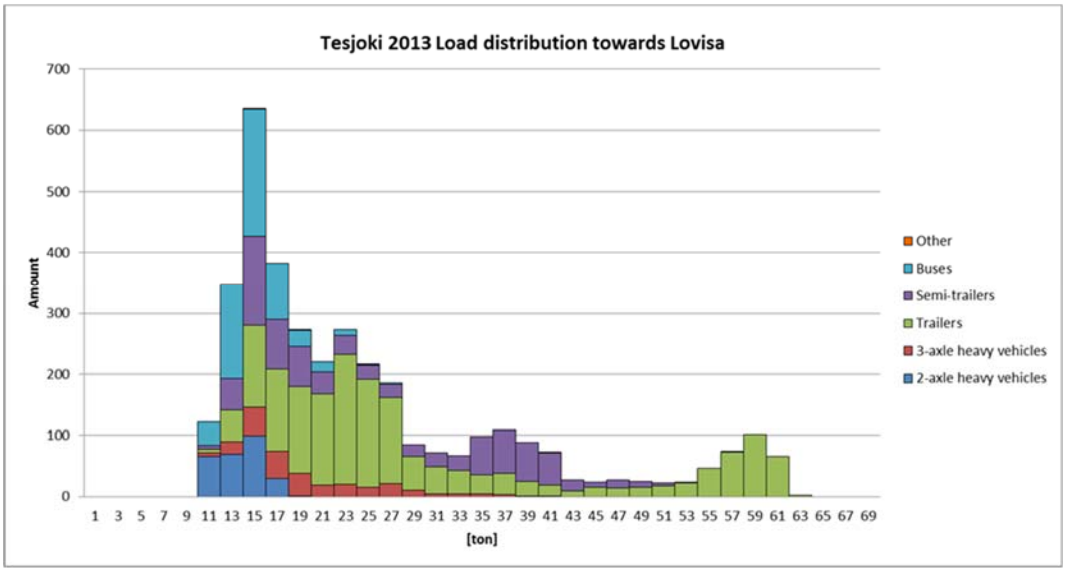



*Figure 21. Load distribution cumulative, towards Lovisa.*

### Overload results

Overloads presented in this section are for vehicles in both directions. From figure 22 and table 10, it can be seen that the percentage of overloaded vehicles is nearly 10% in total. That is, with overloads on (all) gross weight, axles or both. Typical vehicles overloaded are presented in figure 23.

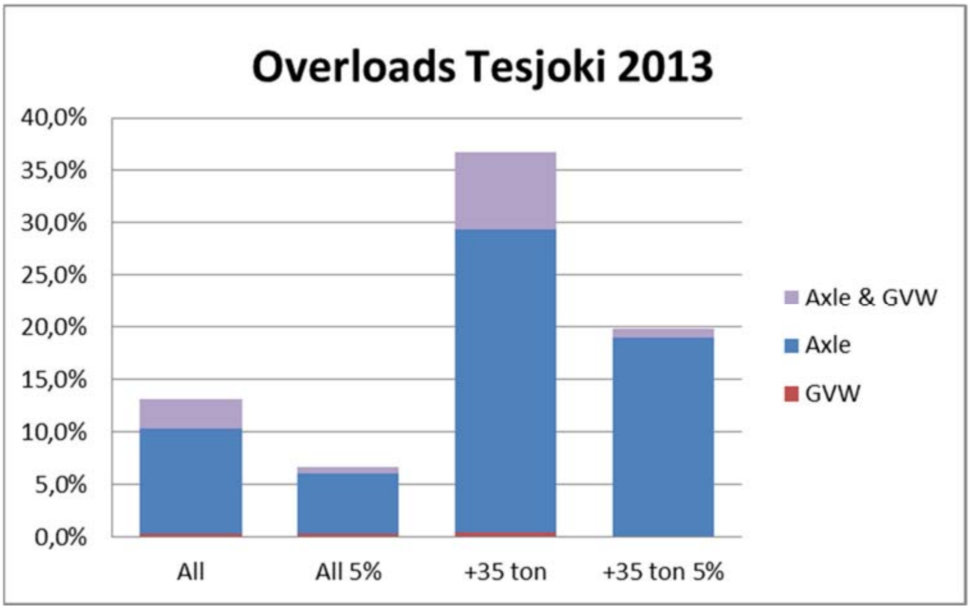



*Figure 22. Overload results from Tesjoki bridge measurement 2013.*

*Table 9. Overload results from Tesjoki bridge measurement 2013.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 10,0% | 0,3% | 2,8% | **13,2%** |
| **All 5%** | 5,7% | 0,3% | 0,7% | **6,7%** |
| **+35t** | 28,9% | 0,4% | 7,3% | **36,7%** |
| **+35t +5%** | 18,9% | 0,1% | 0,8% | **19,8%** |

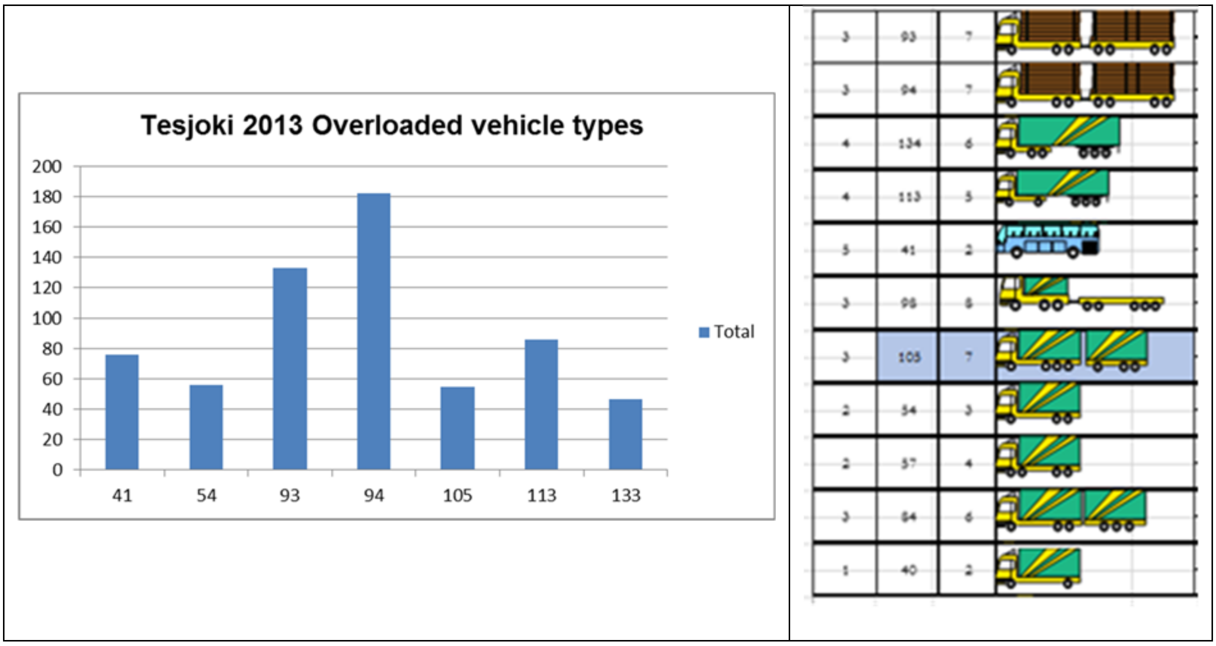



*Figure 23. Tesjoki 2013 typical vehicles overloaded.*

**Comparison between 24 tons and 27 tons limit**

Only vehicles with triple axle were used in this comparison. The table below shows what the overload effect is in percentage difference, when comparing the loading regulations of 24 t and 27t respectively. As expected, implementation of the Finlex upper limit of 27t to the triple axles has reduced the overloads in these vehicle classes significantly.

*Table 10. Comparison between 24 tons and 27 tons limit.*

| OVERLOADING | | 24T | 27T | DIFF |
|---|---|---|---|---|
| Lane 1, towards Kotka | | | | |
| All vehicles | | 1617 | 1617 | **0%** |
| Overloading GVW | | 84 | 84 | **0%** |
| Overloading axles | | 142 | 77 | **-46%** |
| Overload both GVW & axles | | 65 | 31 | **-52%** |
| | | | | |
| Lane 2, towards Lovisa | | | | |
| All vehicles | | 1237 | 1237 | **0%** |
| Overloading GVW | | 67 | 67 | **0%** |
| Overloading axles | | 173 | 107 | **-38%** |
| Overload both GVW & axles | | 57 | 40 | **-30%** |
| | | | | |
| Overloaded vehicles # | | 344 | 264 | **-23%** |
| Overloaded vehicles % | | 12,1% | 9,3% | **-23%** |

# 3.2 Olhava 2013 to 2017

### 3.2.1 Overview, Main Road VT4 (E75/E8)

This bridge is located equi-distant from Oulu in the south to Kemi in the north. The bridge is an underpass for pedestrians and is traffic free. The bridge is slightly uncommon in design, being of a trapezoidal construction (figure 24), giving a free height of 2,8m and a ceiling span of 6,0m. The bridge is quite new, being constructed (re-built) in 2007. Power to the system was supplied from a nearby sub-station.

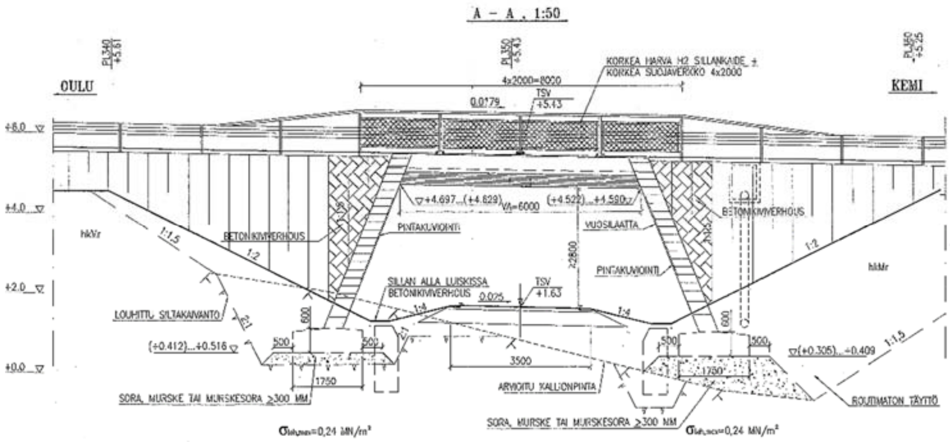
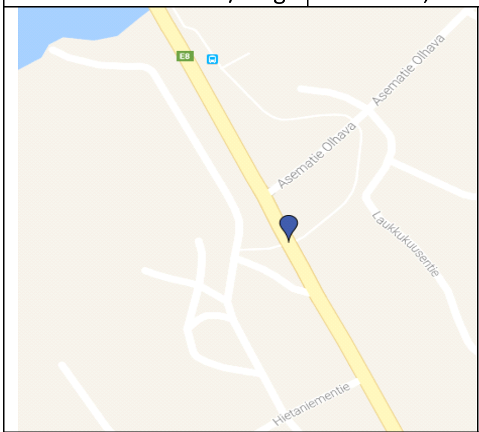



*Figure 24. Olhava bridge.*

*Table 11. Bridge data of Olhava bridge.*

| | |
|---|---|
| Bridge name: | Olhava (Olhavan alikulkukäytävä) |
| Road/Location: | E75/E8 between Kemi and Oulu |
| Lanes: | 1+1 |
| Measured direction: | Both |
| Bridge Id: | O-1548 |
| Bridge type: | |
| Coordinate lat/long: | 65.46243, 25.37541 |





Source: Google.com

*Table 12. Measured traffic data from Olhava bridge measurements 2013 – 2017.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| **Results** | **ESAL** | **# Per day** | **GVW** | **Weight** | **Count** | **Axle** | **GVW** | **Both** |
| 2013 | 1,22 | 858 | 34,61 t | 207 902 t | 6 007 | 13,4% | 0,5% | 1,9% |
| 2014 | 1,39 | 822 | 36,55 t | 210 188 t | 5 751 | 19,5% | 1,8% | 7,0% |
| 2015 | 1,41 | 892 | 36,60 t | 228 653 t | 6 247 | 25,7% | 1,9% | 10,5% |
| 2016 | 1,30 | 733 | 34,28 t | 175 853 t | 5 130 | 10,9% | 5,9% | 9,5% |
| 2017 | 1,56 | 778 | 39,75 t | 216 338 t | 5 443 | 12,5% | 4,1% | 12,2% |

### 3.2.2 Measurement 2013

The instrumentation was initially installed on 26th September 2013, but due to some technical difficulties, was not completely installed and configured until 30th September. Initial influence lines showed some dynamics on the platform edges and this is probably due to the deterioration of the road surface.

*Figure 25. Evidence of the poor surface in Lane 2 (southerly towards Oulu). Cracks and surface deformation are evident.*

The first calibration was made on 30th September using a local aggregate vehicle of axle design 1312. As a triple axled truck is not an ideal calibration vehicle, the 2nd axle was raised to produce a 6 axle vehicle of 1212 formation. The first calibration gave results of: Lane 1 - GVW A5 and Group axles A5, and lane 2: GVW B10 and Group axles B+7. The second calibration took place on 10th October using the same vehicle, and produced results of: Lane 1 - GVW A5 and Group axles A5, lane 2 – GVW B+7 and Group axles B+7.

The variance between the two calibrations (drift) was 0.45% on lane 1, and 0.83% on lane 2. This was an excellent result and shows the bridge and measure had a high degree of stability.

The weather over the period was reasonable with some precipitation. Temperatures were +6°C at the outset and +6°C when the system was dismantled on 8th October.

Measurement results are presented in tables 13 and 14 as accumulative statistics for the vehicle groups on different lanes and in figures 26 and 27 as cumulative load distributions on different lanes.

*Table 13. Accumulative statistics for the vehicle groups, towards Kemi.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 107 | 158 | 2 012 | 383 | 270 | 113 | **3 043** |
| **Speed (ave.)¹** | 79,91 | 77,24 | 83,11 | 81,49 | 79,06 | 83,32 | **82,14** |
| **GVW average** | 13,76 | 22,87 | 41,61 | 31,05 | 15,47 | 47,18 | **36,22** |
| **Total GVW²** | 1 472,32 | 3 613,46 | 83 719,32 | 11 892,15 | 4 176,9 | 5 331,34 | **110 217,46** |
| **ESAL (Ave.)³** | 0,65 | 0,85 | 1,5 | 0,94 | 0,62 | 1,66 | **1,3** |

*Table 14. Accumulative statistics for the vehicle groups, towards Oulu.*

| Vehicle group | 2-axled laden trucks | 3-axled laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 121 | 82 | 1 911 | 466 | 235 | 149 | **2 964** |
| **Speed (ave.)¹** | 79,8 | 75,71 | 80,32 | 79,32 | 81,18 | 69,98 | **79,56** |
| **GVW average** | 13,73 | 20,28 | 35,54 | 35,04 | 14,71 | 44,79 | **32,96** |
| **Total GVW²** | 1 661,33 | 1 662,96 | 67 916,94 | 16 328,64 | 3 456,85 | 6 673,71 | **97 693,44** |
| **ESAL (Ave.)³** | 0,59 | 0,69 | 1,17 | 1,32 | 0,64 | 1,79 | **1,15** |

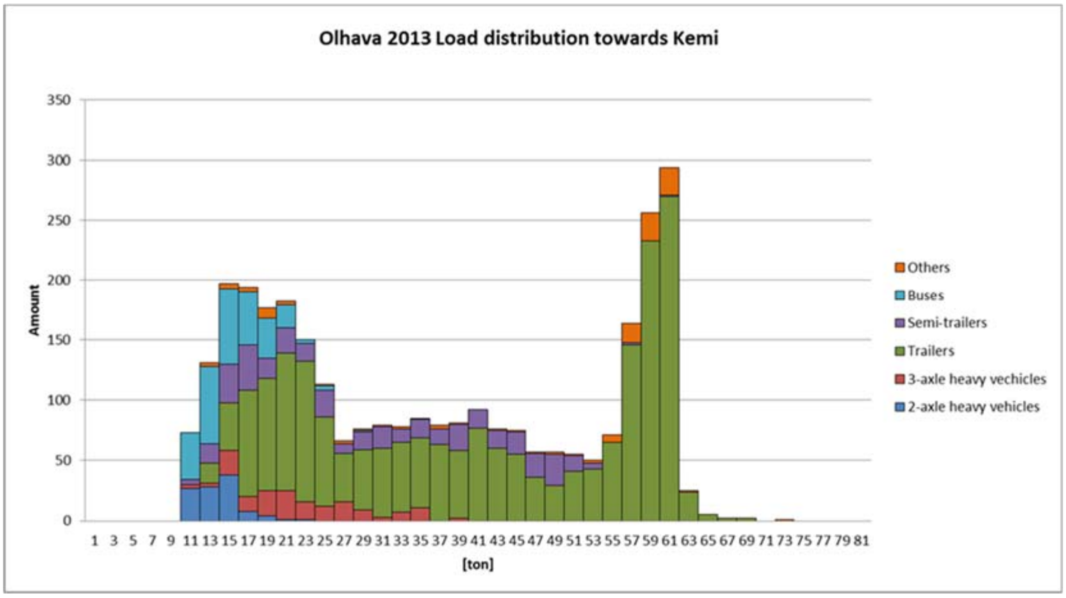



*Figure 26. Load distribution cumulative, towards Kemi.*

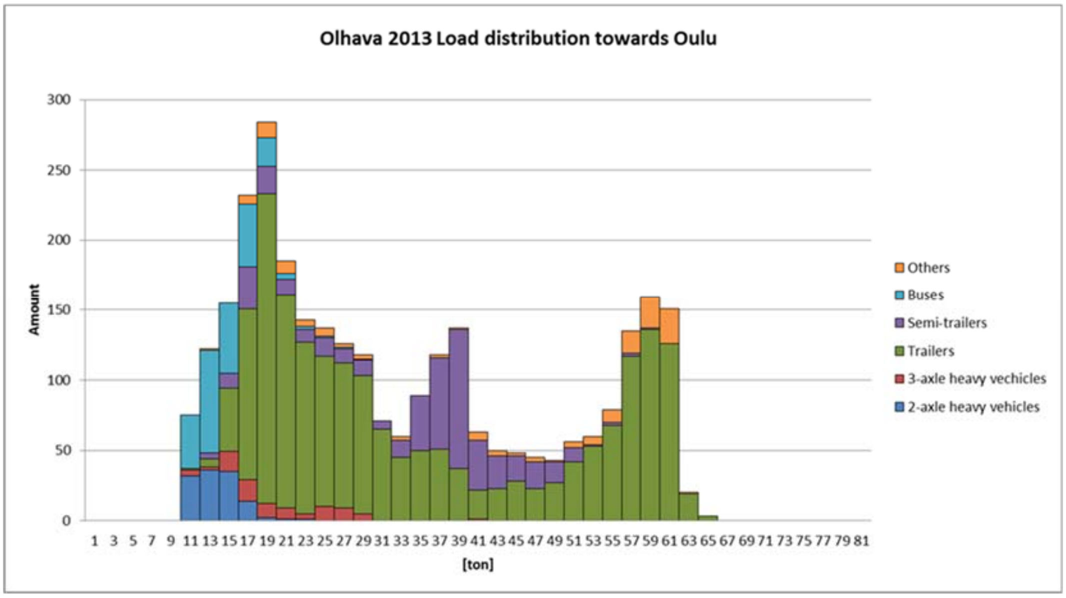



*Figure 27. Load distribution cumulative, towards Oulu.*

### Overload results

Overloads presented in this section are for vehicles in both directions. From figure 28 and table 15 it can be seen that the percentage of all overloaded vehicles is around 18% in total. That is, with overloads on (all) gross weight, axles or both.

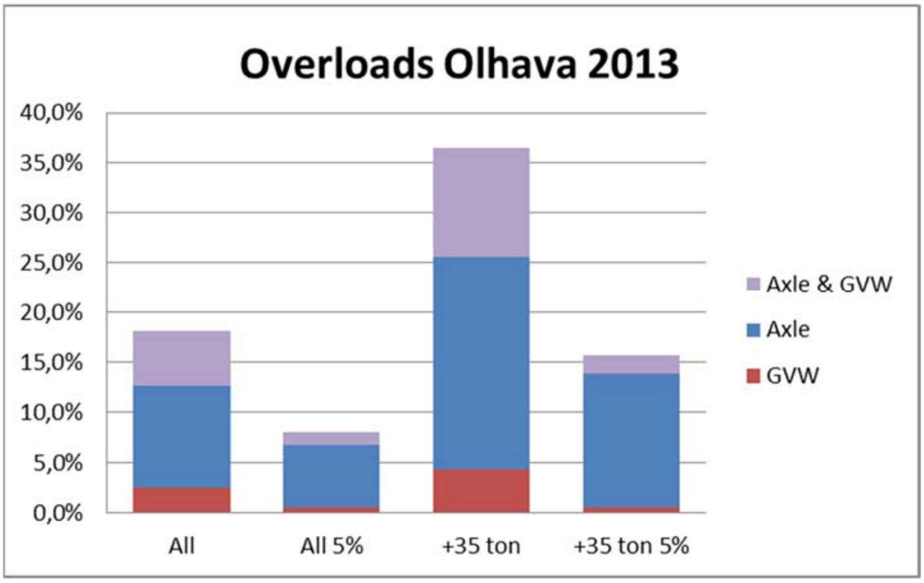



*Figure 28. Overload results from Olhava measurement 2013.*

*Table 15. Overload results from Olhava measurement 2013.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 10,1% | 2,5% | 5,4% | **18,1%** |
| **All 5%** | 6,3% | 0,5% | 1,1% | **7,9%** |
| **+35t** | 21,2% | 4,4% | 10,8% | **36,4%** |
| **+35t +5%** | 13,4% | 0,5% | 1,9% | **15,7%** |

### Comparison between 24 tons and 27 tons limit

Only vehicles with tripe axle were used in this comparison. The table below shows what the overload effect is in percentage difference, when comparing the loading regulations of 24 t and 27t respectively. As expected, implementation of the Finlex upper limit of 27t to the triple axles has reduced the overloads in these vehicle classes significantly.

*Table 16. Comparison between 24 tons and 27 tons limit.*

| OVERLOADING | | 24T | 27T | DIFF |
|---|---|---|---|---|
| Lane 1, towards Kemi | | | | |
| All vehicles | | 1003 | 1003 | **0%** |
| Overloading GVW | | 156 | 156 | **0%** |
| Overloading axles | | 162 | 55 | **-66%** |
| Overload both GVW & axles | | 91 | 31 | **-66%** |
| | | | | |
| Lane 2, towards Oulu | | | | |
| All vehicles | | 1122 | 1122 | **0%** |
| Overloading GVW | | 159 | 159 | **0%** |
| Overloading axles | | 198 | 97 | **-51%** |
| Overload both GVW & axles | | 95 | 44 | **-54%** |
| | | | | |
| Overloaded vehicles # | | 489 | 392 | **-20%** |
| Overloaded vehicles % | | 23,0 | 18,4 | **-20%** |

### 3.2.3 Measurement 2014:

The weather during the assembly of the system was inclement with light snowfall and temperatures of around 0-2 degrees, but this improved over the period and during the days around 6-10 degrees, although there were several sub-zero nights and the temperature during the final calibration and disassembly was around +2 degrees.

The system calibrated on 24$^{th}$ September 2014, and due to logistical reasons was not re-calibrated until 8$^{th}$ October 2014.

The measurement in Olhava shows that the traffic looks similar to continental EU traffic. There are some deviations from the previous year, but this is expected in 'normal' traffic flow measurement.

There are no deviations during the measurement. The measurements were done by Trafikia AB with the SiWIM bridge measurement system, using up-dated MKIII software.

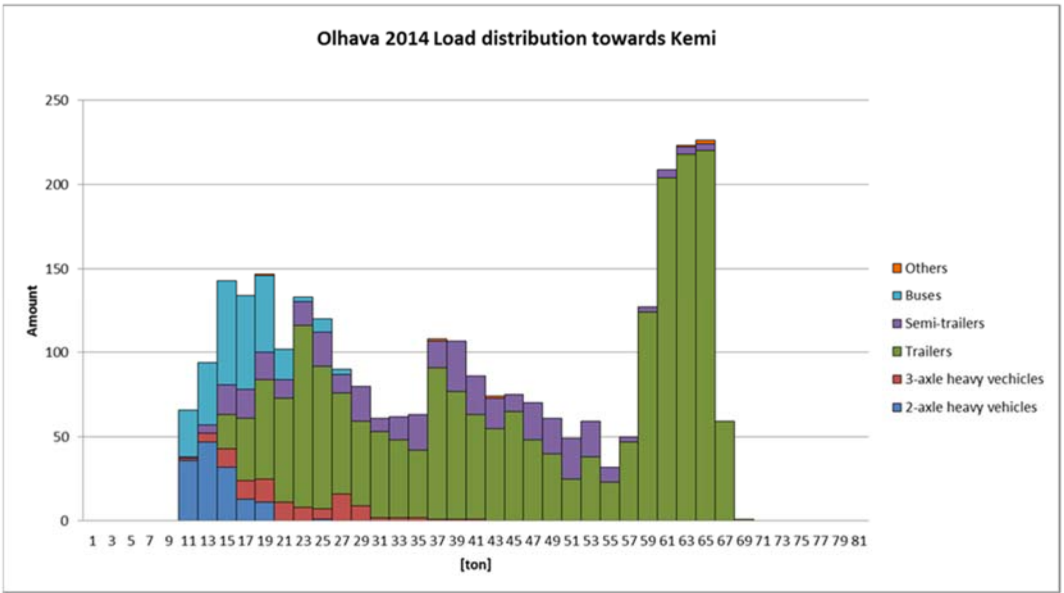
Measurement results are presented in tables 17 and 18 as accumulative statistics for the vehicle groups on different lanes and in figures 29 and 30 as cumulative load distributions on different lanes.

*Table 17. Accumulative statistics for the vehicle groups, towards Kemi.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 140 | 101 | 2 013 | 390 | 261 | 6 | **2 911** |
| **Speed (ave.)[1]** | 79,54 | 79,14 | 81,88 | 80,66 | 77,32 | 85,07 | **81,1** |
| **GVW average** | 13,78 | 22,38 | 46,18 | 36,76 | 16,33 | 48,79 | **39,87** |
| **Total GVW[2]** | 1 929,2 | 2 260,38 | 92 960,34 | 14 336,4 | 4 262,13 | 292,74 | **116 061,57** |
| **ESAL (Ave.)[3]** | 0,64 | 0,86 | 1,83 | 1,35 | 0,83 | 1,93 | **1,59** |

*Table 18. Accumulative statistics for the vehicle groups, towards Oulu.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | | Others | All vehicles |
|---|---|---|---|---|---|---|---|---|
| **Total vehicles** | 99 | 96 | 1 956 | 417 | 272 | | 0 | **2 840** |
| **Speed (ave.)¹** | 81,57 | 78,23 | 80,02 | 79,35 | 78,68 | | 0 | **79,79** |
| **GVW average** | 13,83 | 21,62 | 36,26 | 36,96 | 15,99 | | 0 | **33,15** |
| **Total GVW²** | 1 369,17 | 2 075,52 | 70 924,56 | 15 412,32 | 4 349,28 | | 0 | **94 146** |
| **ESAL (Ave.)³** | 0,64 | 0,75 | 1,22 | 1,43 | 0,82 | | 0 | **1,18** |



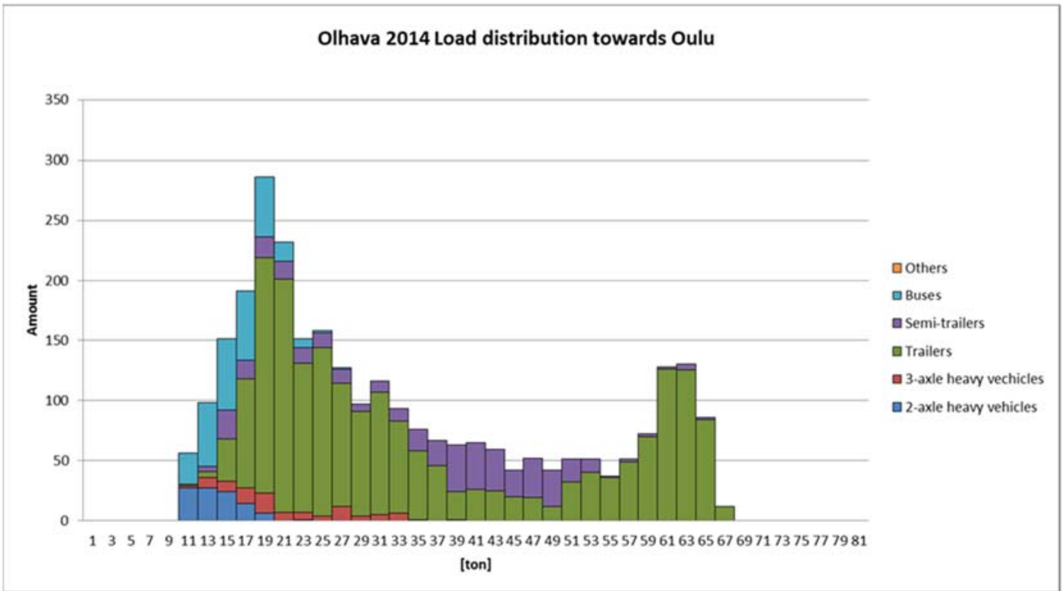




*Figure 30. Load distribution cumulative, towards Oulu.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From figure 31 and table 19 it can be seen that the percentage of all overloaded vehicles is nearly 26% in total. That is, with overloads on (all) gross weight, axles or both.

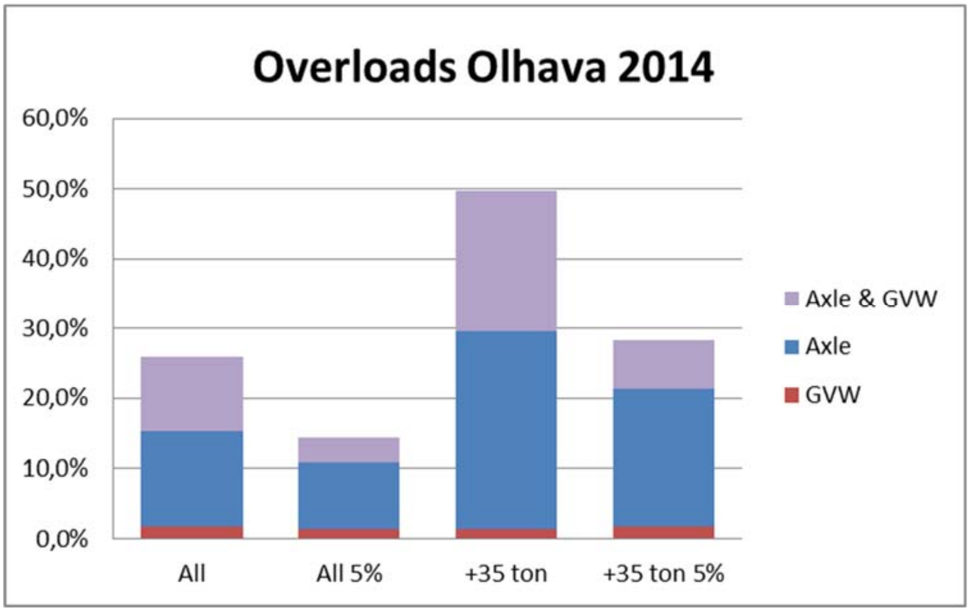



*Figure 31. Overload results from Olhava bridge measurement 2014.*

*Table 19. Overload results from Olhava bridge measurement 2014.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 13,5% | 1,8% | 10,6% | **25,9%** |
| **All 5%** | 9,4% | 1,4% | 3,6% | **14,4%** |
| **+35t** | 28,1% | 1,4% | 20,3% | **49,7%** |
| **+35t +5%** | 19,5% | 1,8% | 7,0% | **28,3%** |

### 3.2.4 Measurement 2015

The weather during the assembly of the system was fine with long periods of sunshine over the whole measurement. Temperatures ranged from 9 degrees (night time) to 22 degrees in the day.

The system was mounted and calibrated on 9th September 2015, and the dismounting and re-calibration took place on the 17th September 2015.

The measurement in Olhava shows that the traffic looks similar to continental EU traffic. The results show a consistency in the traffic when comparing previous results, with the frequency of "new" vehicle configurations as per the Finlex vehicle classifications being more significant.

Measurement results are presented in tables 20 and 21 as accumulative statistics for the vehicle groups on different lanes and in figures 32 and 33 as cumulative load distributions on different lanes.

*Table 20. Accumulative statistics for the vehicle groups, towards Kemi.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 151 | 129 | 1 962 | 495 | 333 | 35 | **3105** |
| Speed (ave.)¹ | 80,71 | 81,59 | 83,48 | 81,95 | 78,78 | 83,58 | **82,52** |
| GVW average | 13,8 | 22,46 | 47,82 | 38,12 | 16,36 | 63,07 | **40,37** |
| Total GVW² | 2 083,8 | 2 897,34 | 93 822,84 | 18 869,4 | 5 447,88 | 2 207,45 | **125 348,9** |
| ESAL (Ave.)³ | 0,72 | 0,81 | 1,95 | 1,34 | 0,9 | 2,59 | **1,64** |

*Table 21. Accumulative statistics for the vehicle groups, towards Oulu.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 108 | 112 | 2 176 | 406 | 311 | 29 | **3 142** |
| Speed (ave.)¹ | 81,9 | 79,88 | 80,46 | 80,62 | 80,47 | 67,23 | **80,39** |
| GVW average | 13,67 | 23,11 | 35,91 | 35,34 | 15,95 | 62,52 | **32,88** |
| Total GVW² | 1 476,36 | 2 588,32 | 78 140,16 | 14 348,04 | 4 960,45 | 1 813,08 | **103 309** |
| ESAL (Ave.)³ | 0,64 | 0,94 | 1,23 | 1,26 | 0,78 | 3,39 | **1,18** |

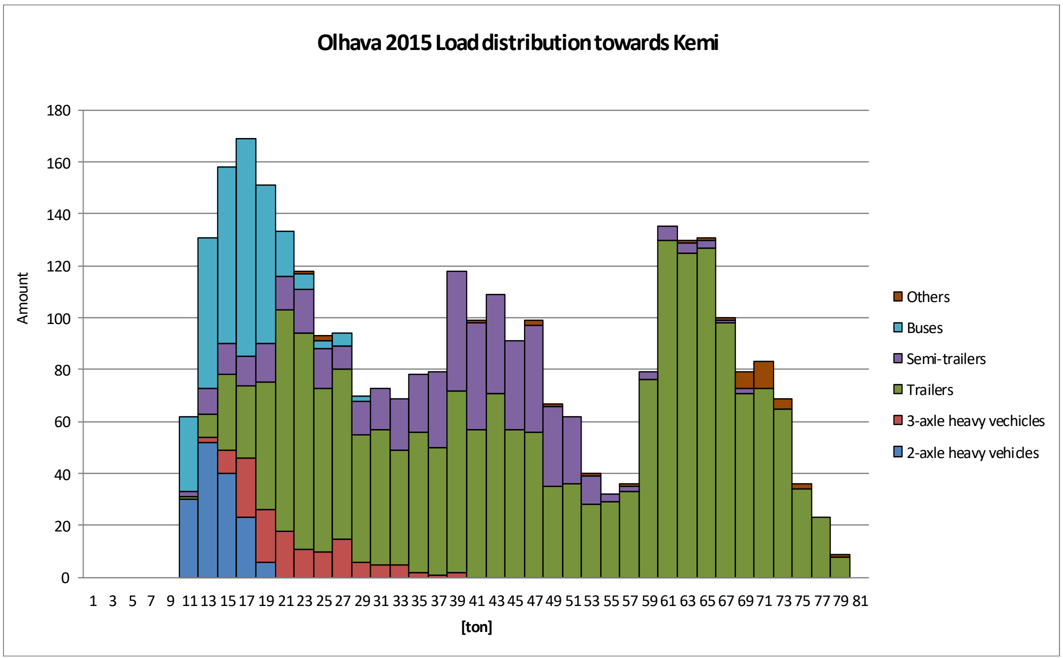



*Figure 32.* *Load distribution cumulative, towards Kemi.*

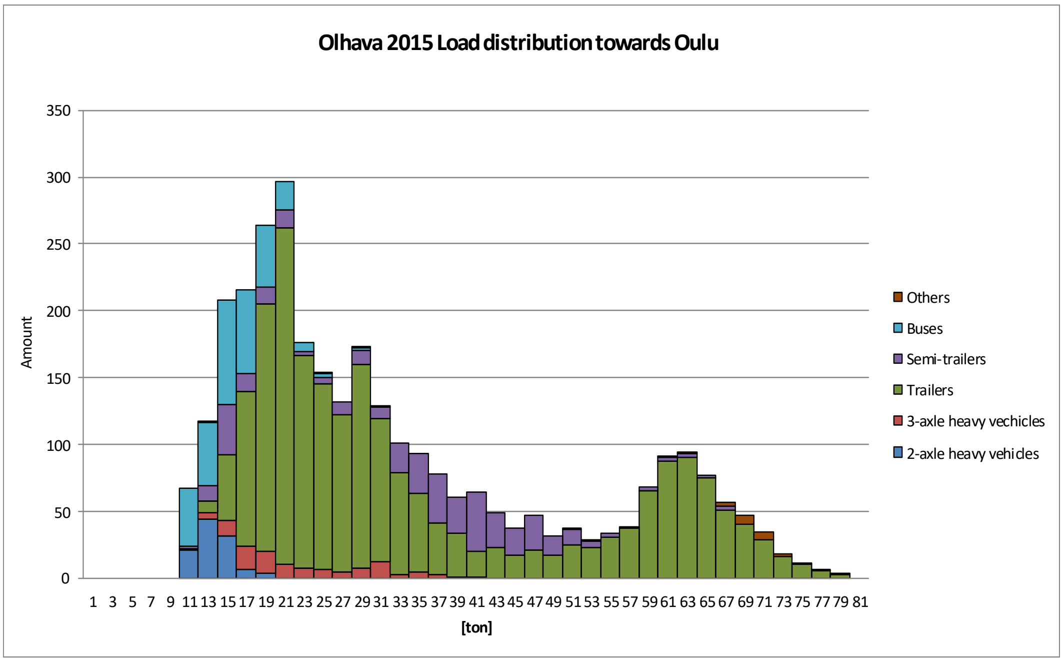



*Figure 33.* *Load distribution cumulative, towards Oulu.*

### Overload results

Overloads presented in this section are for vehicles in both directions. From figure 34 and table 22, it can be seen that the percentage of all overloaded vehicles is nearly 27% in total. That is, with overloads on (all) gross weight, axles or both.

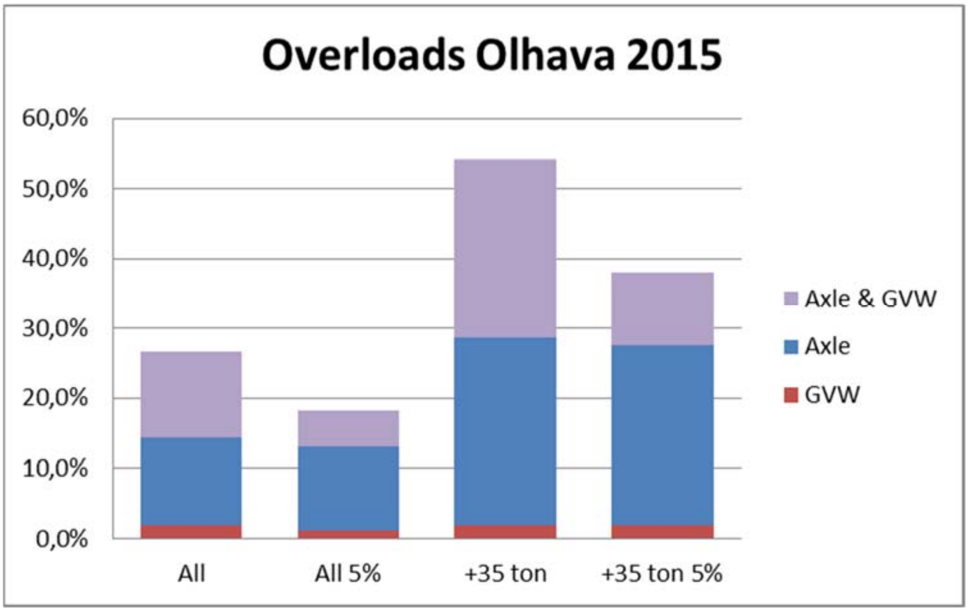



*Figure 34. Overload results from Olhava bridge measurement 2015.*

*Table 22. Overload results from Olhava bridge measurement 2015.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 12,5% | 1,9% | 12,2% | **26,6%** |
| **All 5%** | 11,9% | 1,2% | 5,1% | **18,2%** |
| **+35t** | 26,8% | 1,9% | 25,5% | **54,2%** |
| **+35t +5%** | 25,7% | 1,9% | 10,5% | **38,1%** |

### 3.2.5 Measurement 2016:

There is an increased number of class 140's in the form of 2-2-2-2, 2-2-2-1 and 1-2-2-4. All reference values are very similar to last year's values (average weight, weight of the first axle, ESAL value, % of overloading, vehicle type representation, etc.) but the number of vehicles overall is lower than previous year; 5088 vehicles vs. 6247 in 2015, some 20% drop. We can't find any kind of failure in measurement, data inconsistency or anything else, just lower number of vehicles.

The measurement in Olhava shows that the traffic looks similar to continental EU traffic. The results show a consistency in the traffic when comparing previous results, with the frequency of "new" vehicle configurations as per the Finlex vehicle classifications being more significant.

From the *load distribution diagrams* below it can be seen that there is limited loading of vehicles in the southern direction towards Oulu, and this is consistent over the years. The loading in the northerly direction, with the new regulations coming into effect, can now be significantly detected, and although there are a reduced number of vehicles this year, the trending towards higher capacity loads can be seen.

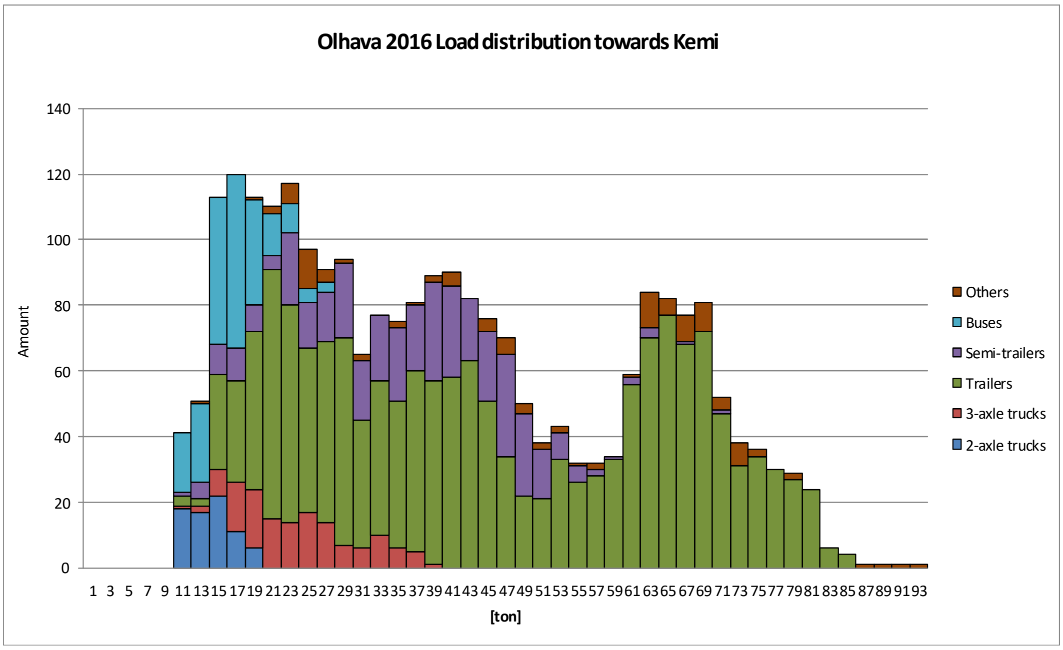
Measurement results are presented in tables 23 and 24 as accumulative statistics for the vehicle groups on different lanes and in figures 35 and 36 as cumulative load distributions on different lanes.

*Table 23. Accumulative statistics for the vehicle groups, towards Kemi.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 74 | 139 | 1 580 | 383 | 201 | 110 | **2 489** |
| **Speed (ave.)¹** | 45,7 | 44,79 | 44,65 | 45,1 | 43,95 | 44,34 | **44,69** |
| **GVW average** | 14,13 | 23,96 | 46,66 | 36,93 | 16,68 | 51,71 | **40,69** |
| **Total GVW²** | 1 045,62 | 3 330,44 | 73 722,8 | 14 144,19 | 3 352,68 | 5 688,1 | **101 277,41** |
| **ESAL (Ave.)³** | 0,76 | 1,01 | 1,88 | 1,23 | 0,85 | 1,94 | **1,62** |

*Table 24. Accumulative statistics for the vehicle groups, towards Oulu.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi- Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 261 | 130 | 1 440 | 423 | 293 | 54 | **2 641** |
| **Speed (ave.)¹** | 46,31 | 46,89 | 43,76 | 42,8 | 46,49 | 41,02 | **44,29** |
| **GVW average** | 13,95 | 19,78 | 32,29 | 32,47 | 16,41 | 49,26 | **27,99** |
| **Total GVW²** | 3 640,95 | 2 571,4 | 46 497,6 | 13 734,81 | 4 808,13 | 2 660,04 | **73 921,59** |
| **ESAL (Ave.)³** | 0,69 | 0,62 | 1,05 | 1,03 | 0,82 | 2,36 | **0,97** |



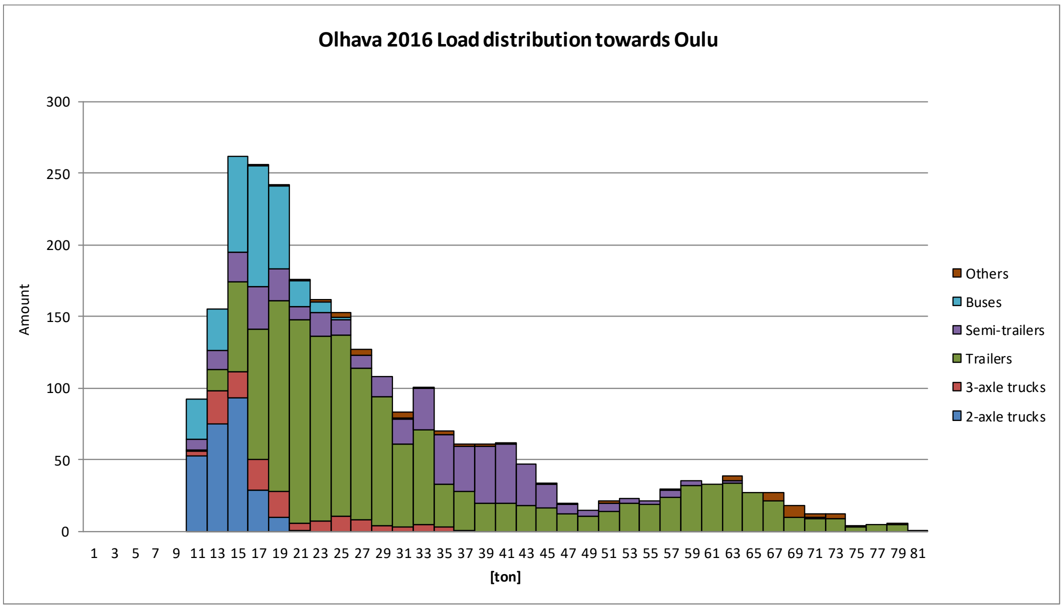



*Figure 36. Load distribution cumulative, towards Oulu.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From the illustration, it can be seen that the percentage of all overloaded vehicles is around 22% in total. That is, with overloads on (all) gross weight, axles or both.

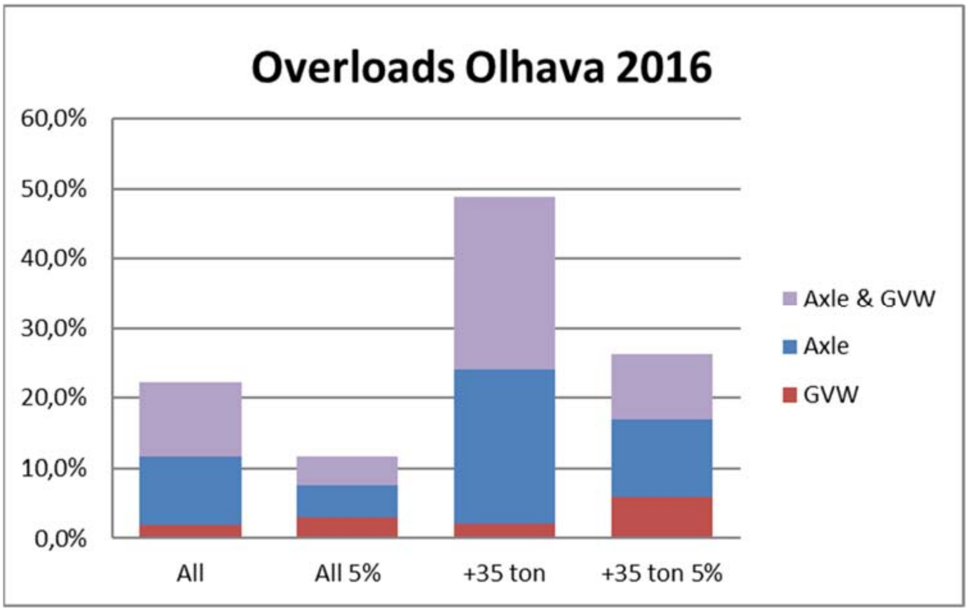



*Figure 37. Overload results from Olhava bridge measurement 2016.*

*Table 25. Overload results from Olhava bridge measurement 2016.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 9,8% | 1,8% | 10,7% | **22,3%** |
| **All 5%** | 4,6% | 2,9% | 4,0% | **11,5%** |
| **+35t** | 22,1% | 2,0% | 24,8% | **48,9%** |
| **+35t +5%** | 10,9% | 5,9% | 9,5% | **26,3%** |

### 3.2.6 Measurement 2017:

The weather over the period was mostly overcast with also some rain/clear and sunny. The temperature range was between +5°C to +10°C.

The system was installed on 12th September and also calibrated this day. Calibrations showed accuracy level of B+/B. The system was re-calibrated on 26th September and dismantled the same day. The analysis period was taken between 19th September and 25th September.

There are a difference of around 700 vehicles over the measured period direction wise, with the lesser vehicle amount towards Kemi. We can't find any kind of failure in measurement, data inconsistency or anything else, just lower number of vehicles.

From the *load distribution diagrams* below, it can be seen that there is limited loading of vehicles in the southern direction towards Oulu, and this is consistent over the years. The loading in the northerly direction, with the new regulations coming into effect, can now be significantly detected, and although there are a reduced number of vehicles this year, the trending towards higher capacity loads can be seen.

Measurement results are presented in tables 26 and 27 as accumulative statistics for the vehicle groups on different lanes and in figures 38 and 39 as cumulative load distributions on different lanes.

*Table 26. Accumulative statistics for the vehicle groups, towards Kemi.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 37 | 73 | 1 746 | 231 | 226 | 55 | **2 386** |
| **Speed (ave.)[1]** | 87,44 | 85,08 | 87,06 | 85,85 | 83 | 84,32 | **86,41** |
| **GVW average** | 15,31 | 24,99 | 51,7 | 44 | 16,71 | 62,78 | **46,12** |
| **Total GVW[2]** | 566,47 | 1 824,27 | 90 268,2 | 10 164 | 3 776,46 | 3 452,9 | **110 042,32** |
| **ESAL (Ave.)[3]** | 0,8 | 1,11 | 2,18 | 1,75 | 0,75 | 3,53 | **1,96** |

*Table 27. Accumulative statistics for the vehicle groups, towards Oulu.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi- Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 100 | 101 | 2 049 | 465 | 297 | 63 | **3 107** |
| Speed (ave.)[1] | 80,19 | 78,67 | 78,99 | 79,36 | 79,1 | 79,03 | **79,06** |
| GVW average | 13,97 | 21,36 | 38,08 | 36,04 | 16,13 | 50,36 | **34,21** |
| Total GVW[2] | 1397 | 2 157,36 | 78 025,92 | 16 758,6 | 4 790,61 | 3 172,68 | **106 290,47** |
| ESAL (Ave.)[3] | 0,59 | 0,85 | 1,31 | 1,26 | 0,67 | 2,7 | **1,22** |

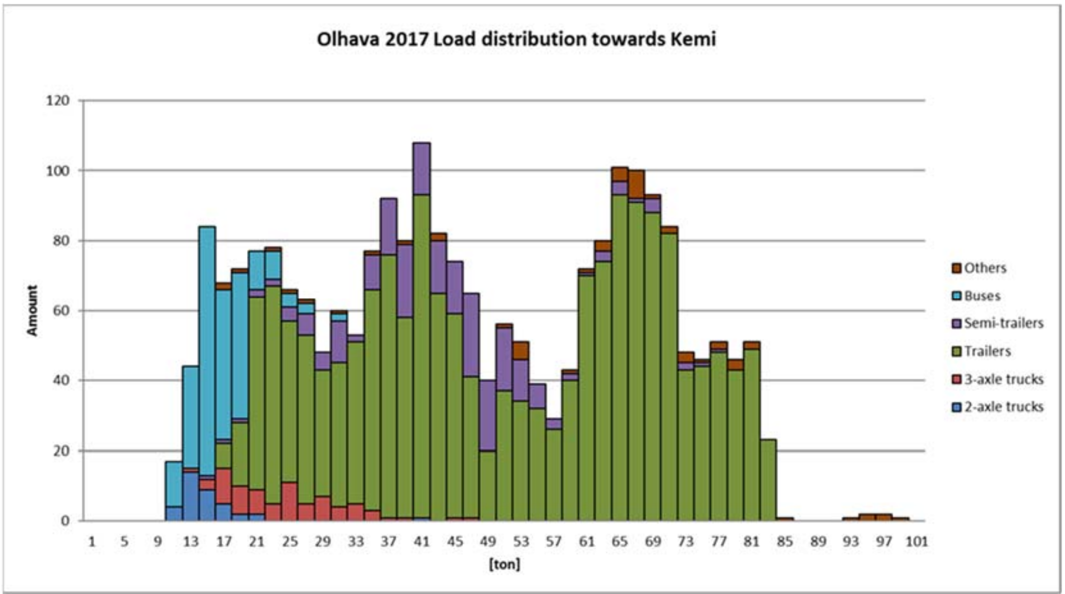



*Figure 38. Load distribution cumulative, towards Kemi.*

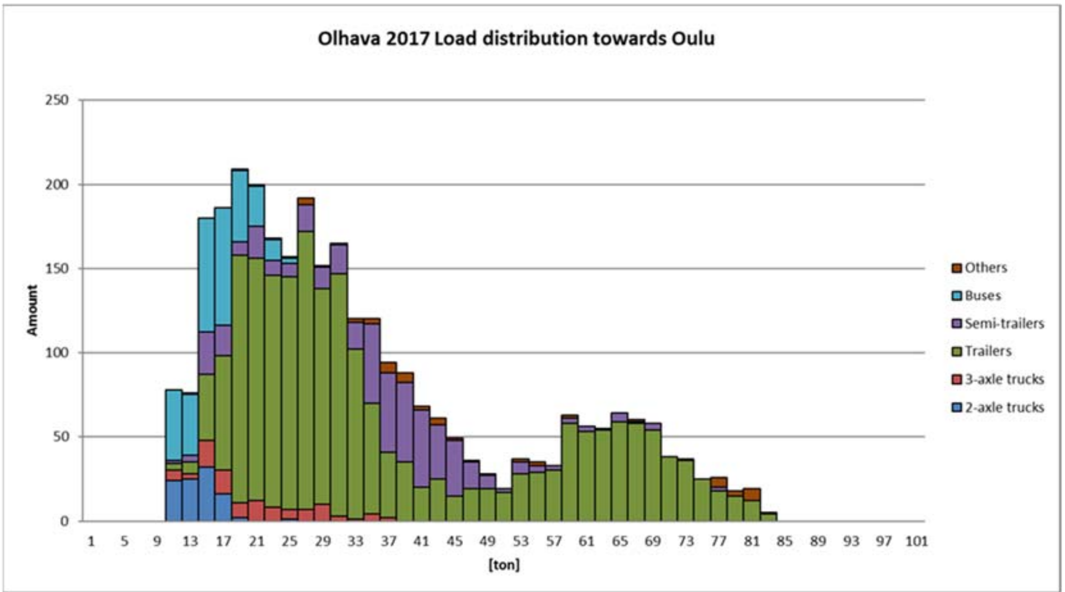



*Figure 39. Load distribution cumulative, towards Oulu.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From the illustration, it can be seen that the percentage of all overloaded vehicles is around 28% in total. That is, with overloads on (all) gross weight, axles or both.

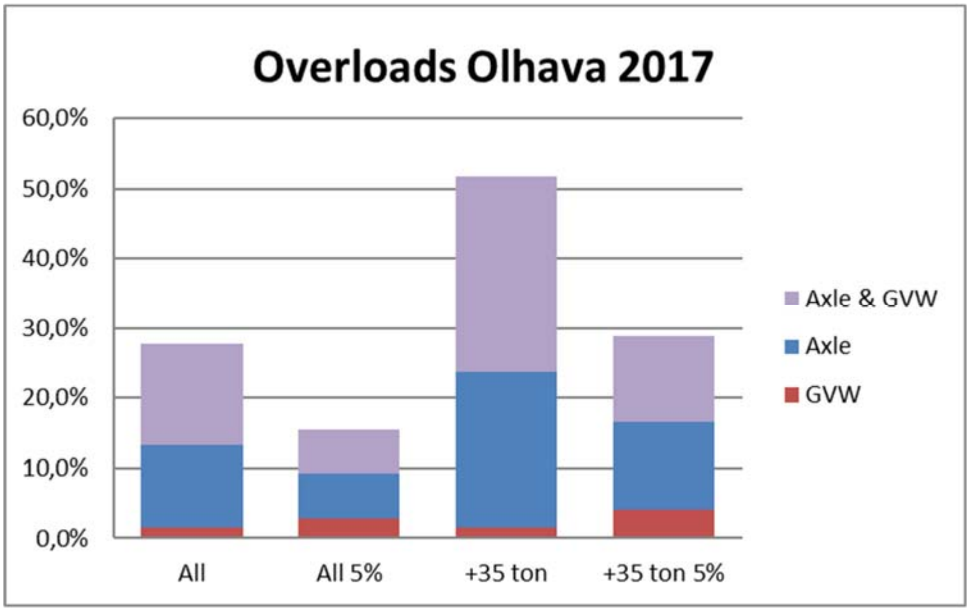



*Figure 40. Overload results from Olhava bridge measurement 2017.*

*Table 28. Overload results from Olhava bridge measurement 2017.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 11,6% | 1,6% | 14,5% | **27,7%** |
| **All 5%** | 6,4% | 2,8% | 6,2% | **15,5%** |
| **+35t** | 22,2% | 1,5% | 28,0% | **51,7%** |
| **+35t +5%** | 12,5% | 4,1% | 12,2% | **28,9%** |

# 3.3 Kaarina 2014 and 2016

### 3.3.1 Overview, Road 180

The site is situated just south of Kaarina on road 180. Traffic was measured in both directions. The northbound driving direction is towards Kaarina and the southbound driving direction is towards Korpo and the archipelago.

Since the original survey of this bridge in 2011, traffic lights were installed at the nearby junction. This did not appear to have a significant effect on the traffic flow, especially towards Kaarina, where the vehicles were passing the bridge at reasonable speed – but there may have been a slight effect in the southerly direction during peak periods when there was very occasionally standing traffic.

*Table 29. Bridge data of Kaarina bridge.*

| | |
|---|---|
| Bridge name: | Kaarina (Puistotien alikulkukytävä) |
| Road/Location: | Road 180 between Kaarina and Kirjala |
| Lanes: | 1 + 1 |
| Measured direction: | Both |
| Bridge Id: | |
| Bridge type: | |
| Coordinate lat/long: | 60.38794, 22.39012 |


Source: Google.com

*Table 30. Measured traffic data from Äänekoski bridge measurements 2014 and 2016.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| **Results** | **ESAL** | **# Per day** | **GVW** | **Weight** | **Amount** | **Axle** | **GVW** | **Both** |
| 2014 | 1,06 | 481 | 27,20 t | 91 571 | 3 367 | 25,9% | 3,9% | 10,4% |
| 2016 | 1,20 | 515 | 27,88 | 100 536 | 3 606 | 28,0% | 3,7% | 37,2% |

### 3.3.2 Measurement 2014

The weather over the period was reasonable with some light precipitation. Temperatures were +10°C to +16°C when the system was dismantled on 10th June.

The measurement in Kaarina shows that the traffic here is typical of supply transport and distribution, i.e. a high incidence of rigid axle vehicles with 2/3 axles. Although several heavier vehicles can be seen, connecting with the local industries. The 2/3 axle vehicles can be seen quite clearly in the tables below (many vehicles showing in the bus classification, which is a graphical representation of vehicle groups 40 and 41) and the load distributions are indicative being between 5 and 30 tons.

There are no deviations during measurement.

*Figure 41.* *Calibration vehicle Kaarina 2014.*

Measurement results are presented in tables 31 and 32 as accumulative statistics for the vehicle groups on different lanes and in figures 42 and 43 as cumulative load distributions on different lanes.

*Table 31.* *Accumulative statistics for the vehicle groups lane 1, towards North.*

| Vehicle group | 2-axl. laden trucks | 3-axl. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 211 | 180 | 845 | 122 | 410 | 14 | **1 782** |
| **Speed (ave.)[1]** | 51,62 | 55,97 | 57,23 | 56,1 | 54,25 | 69,36 | **55,77** |
| **GVW average** | 13,29 | 20,35 | 47,86 | 29,76 | 13,68 | 33,46 | **31,77** |
| **Total GVW[2]** | 2 804,19 | 3 663,00 | 40 441,70 | 3 630,72 | 5 608,80 | 468,44 | **56 614,14** |
| **ESAL (Ave.)[3]** | 0,58 | 0,61 | 2,18 | 0,94 | 0,59 | 1,15 | **1,38** |

*Table 32. Accumulative statistics for the vehicle groups lane 2, towards South.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 195 | 148 | 680 | 132 | 399 | 31 | **1 585** |
| Speed (ave.)[1] | 54,36 | 61,41 | 58,56 | 60,81 | 56,57 | 73,11 | **58,28** |
| GVW average | 12,67 | 20,93 | 28,48 | 24,4 | 13,71 | 42,97 | **22,06** |
| Total GVW[2] | 2 470,65 | 3 097,64 | 19 366,40 | 3 220,80 | 5 470,29 | 1 332,07 | **34 965,10** |
| ESAL (Ave.)[3] | 0,47 | 0,69 | 0,84 | 0,56 | 0,57 | 1,14 | **0,69** |

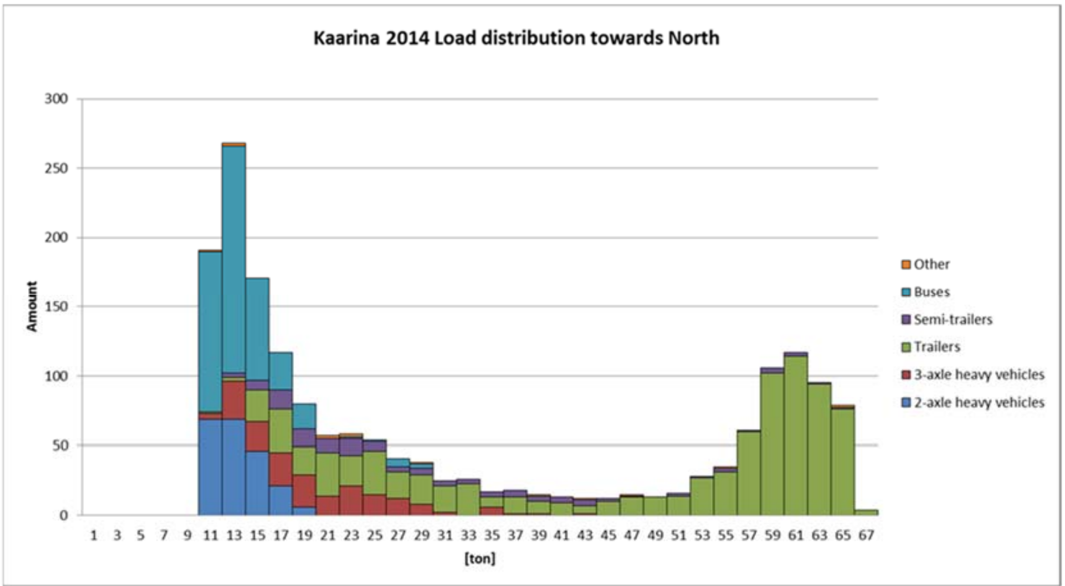



*Figure 42. Load distribution cumulative, towards North.*

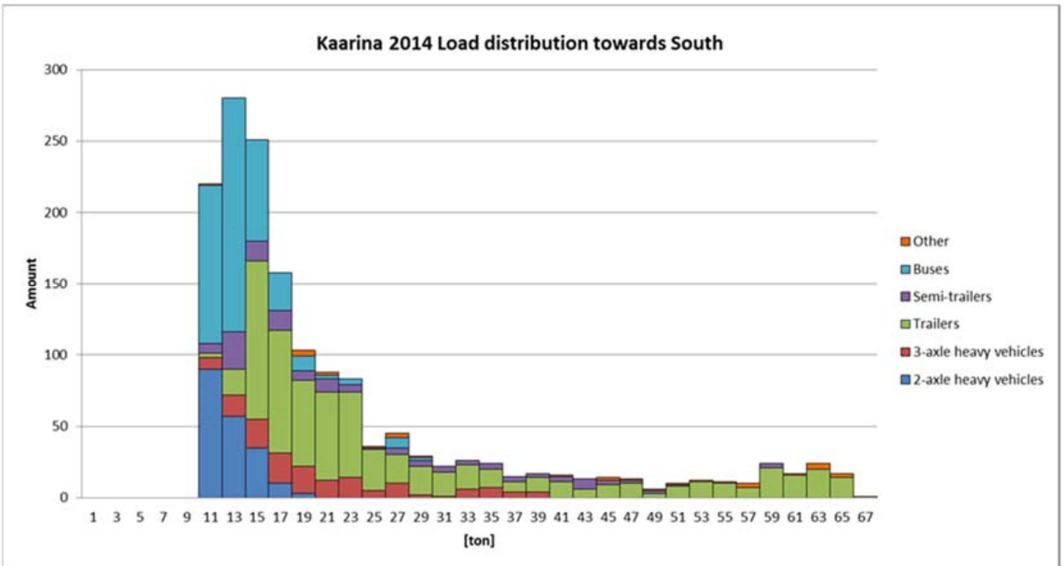



*Figure 43. Load distribution cumulative, towards South.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From figure 44 and table 33, it can be seen that the percentage of overloaded vehicles is nearly 20% in total. That is, with overloads on (all) gross weight, axles or both.

Most of the '+ *35t overloaded 0% tolerance'* overloaded vehicles are just slightly over the limit but they are still overloaded and this give the high percentages.

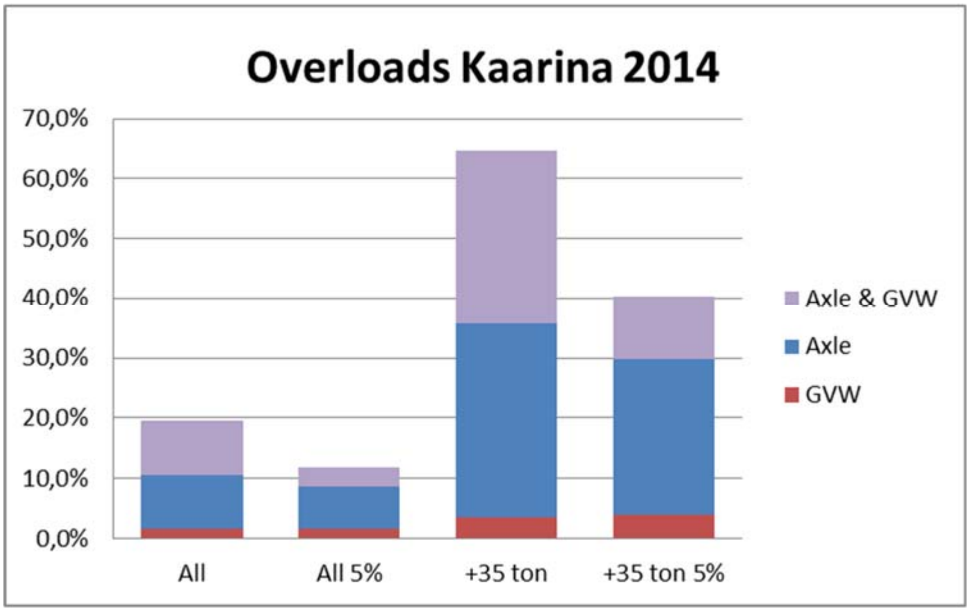



*Figure 44. Overload results from Kaarina bridge measurement 2014.*

*Table 33. Overload results from Kaarina bridge measurement 2014.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 9,1% | 1,6% | 8,8% | **19,5%** |
| **All 5%** | 7,0% | 1,6% | 3,3% | **11,9%** |
| **+35t** | 32,2% | 3,5% | 28,9% | **64,7%** |
| **+35t +5%** | 25,9% | 3,9% | 10,4% | **40,2%** |

### 3.3.3 Measurement 2016

This report is re-processed results with weights starting at +10 tons and upwards. Also the new Finnish vehicle classification table, which contains recently added Finnish vehicles and special transport vehicles, are used. This new vehicle classification table also complies with Eurocodes and Finlex regulations.

We noticed several 2-2-2-2 vehicles, that do not fit classification (higher axle distances), so they become class 140. Also detected are a high number of (over 10) 5-axle cranes (sometimes as 1-2-2, other times as 5-axle group) with axle weights of about 12t each.

*Figure 45. Calibration vehicle Kaarina 2016.*

Measurement results are presented in tables 34 and 35 as accumulative statistics for the vehicle groups on different lanes and in figures 46 and 47 as cumulative load distributions on different lanes.

*Table 34. Accumulative statistics for the vehicle groups lane 1, towards North.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 329 | 207 | 719 | 158 | 332 | 88 | **1 924** |
| **Speed (ave.)[1]** | 52,21 | 55,18 | 56,35 | 54,16 | 53,92 | 57,87 | **54,98** |
| **GVW average** | 13,99 | 22,15 | 51,23 | 29,95 | 15,27 | 45,73 | **31,11** |
| **Total GVW[2]** | 4 602,71 | 4 585,05 | 36 834,37 | 4 732,1 | 5 069,64 | 4 024,24 | **59 855,64** |
| **ESAL (Ave.)[3]** | 0,73 | 0,9 | 2,79 | 1,15 | 0,67 | 2,13 | **1,57** |

*Table 35. Accumulative statistics for the vehicle groups lane 2, towards South.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 268 | 201 | 657 | 152 | 365 | 130 | **1 806** |
| **Speed (ave.)¹** | 53,52 | 57,19 | 56,53 | 58,2 | 56,39 | 64,27 | **56,88** |
| **GVW average** | 13,09 | 21,92 | 28,95 | 22,25 | 14,67 | 38,6 | **22,53** |
| **Total GVW²** | 3 508,12 | 4 405,92 | 19 020,15 | 3 382 | 5 354,55 | 5 018 | **40 689,18** |
| **ESAL (Ave.)³** | 0,48 | 0,79 | 0,9 | 0,49 | 0,43 | 1,54 | **0,73** |

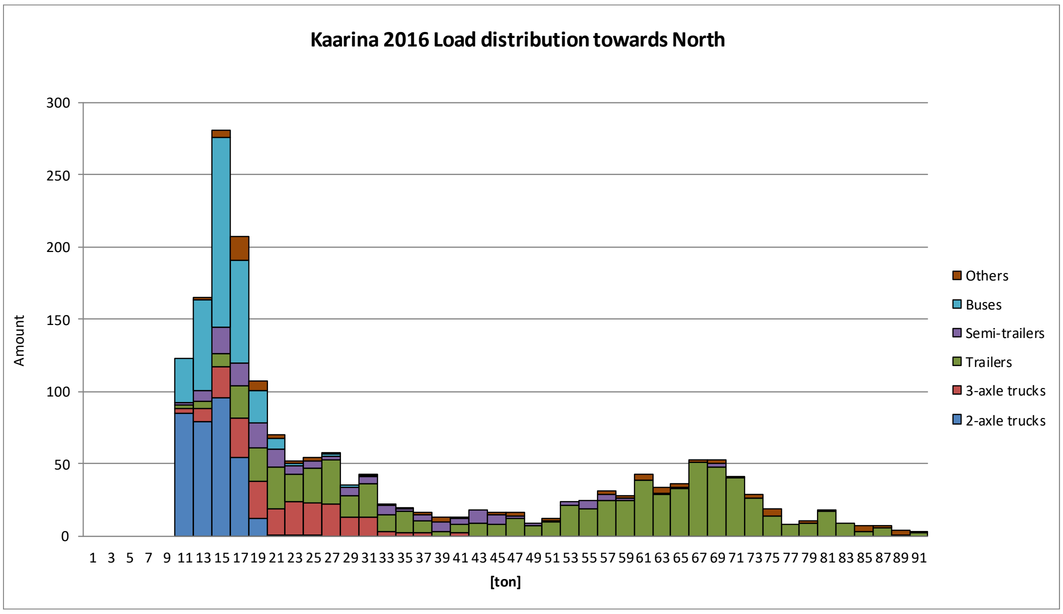



*Figure 46. Load distribution cumulative, towards North.*

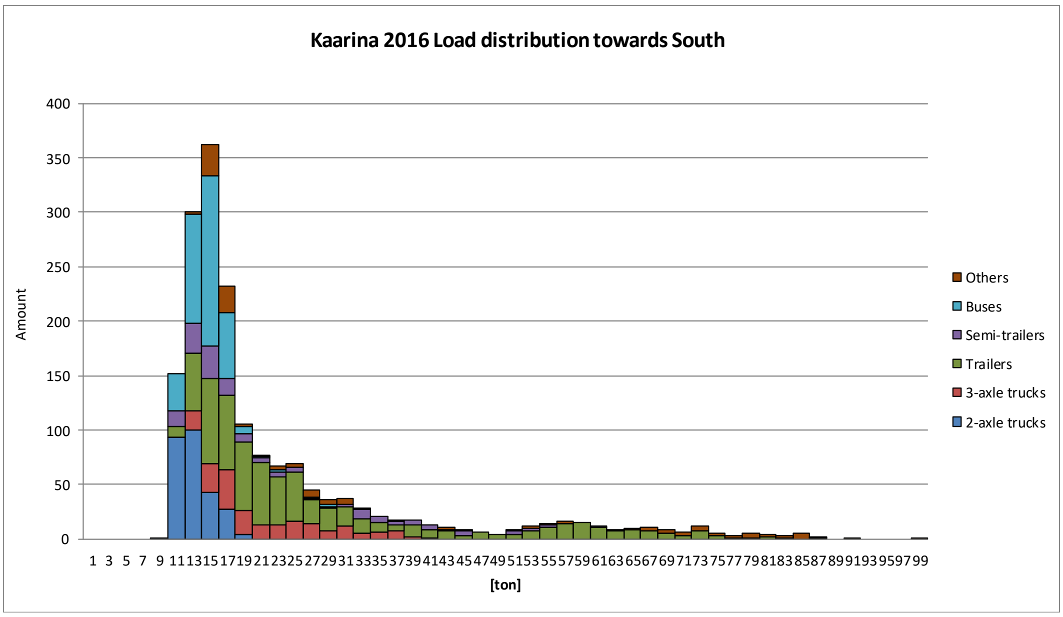



*Figure 47. Load distribution cumulative, towards South.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From figure 48 and table 36, it can be seen that the percentage of overloaded vehicles is about 22% in total. That is, with overloads on (all) gross weight, axles or both.

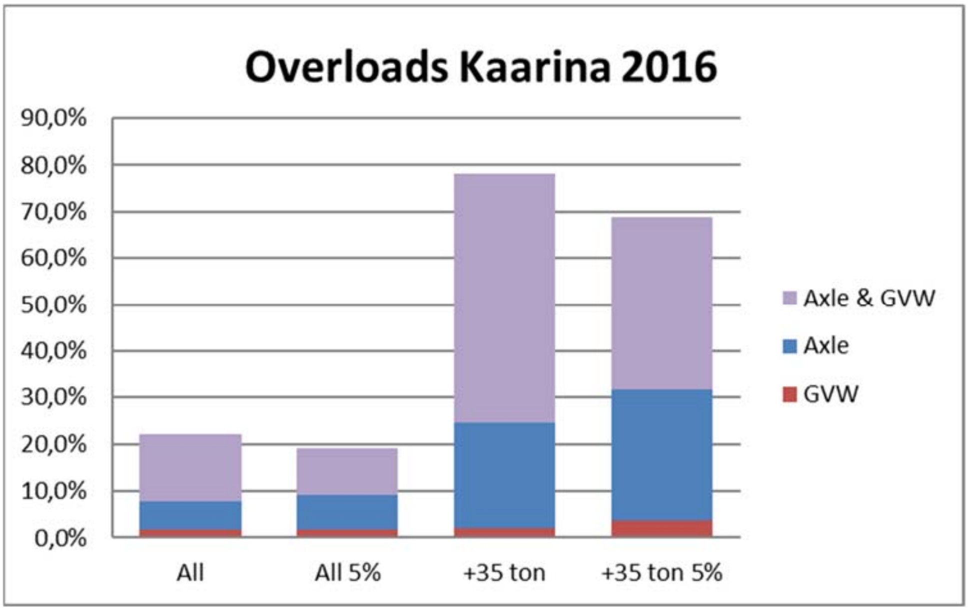



*Figure 48. Overload results from Kaarina bridge measurement 2016.*

*Table 36. Overload results from Kaarina bridge measurement 2016.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 6,3% | 1,6% | 14,3% | **22,2%** |
| **All 5%** | 7,4% | 1,7% | 9,9% | **19,0%** |
| **+35t** | 22,4% | 2,1% | 53,6% | **78,1%** |
| **+35t +5%** | 28,0% | 3,7% | 37,2% | **68,9%** |

# 3.4 Äänekoski 2014 to 2016

### 3.4.1 Overview, Highway 4

The site is situated just north of Äänekoski on highway 4. Traffic was measured in both directions. The northbound driving direction is towards Oulu and the southbound driving direction is towards Jyväskylä. The measurement in Äänekoski shows that the traffic looks similar to continental EU traffic.

*Table 37. Bridge data of Äänekoski bridge.*

| | |
|---|---|
| Bridge name: | Äänekoski (Mämmen alikulkukäytävä) |
| Road/Location: | Highway 4, north of Äänekoski near Mämme |
| Lanes: | 1 + 1 |
| Measured direction: | Both |
| Bridge Id: | |
| Bridge type: | |
| Coordinate lat/long: | 62.64571, 25.70867 |


Source: Google.com

*Table 38. Measured traffic data from Äänekoski bridge measurements 2014–2016.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| **Results** | **ESAL** | **# Per day** | **GVW** | **Weight** | **Amount** | **Axle** | **GVW** | **Both** |
| 2014 | 1,54 | 690 | 32,44 t | 156 611 t | 4 828 | 7,0% | 0,7% | 0,3% |
| 2015 | 2,36 | 772 | 36,19 t | 195 620 t | 5 405 | 16,0% | 2,3% | 3,3% |
| 2016 | 1,89 | 756 | 41,66 t | 220 514 t | 5 293 | 26,6% | 1,4% | 21,7% |

*Figure 49. Äänekoski bridge from north and west.*

### 3.4.2 Measurement 2014

The system was installed at this measurement point on 5th June 2014 and the calibration took place on the 6th June. The weather over the period was reasonable with some precipitation. Temperatures were +10°C to +16°C during the period and the system was dismantled on 12th June 2014.

Measurement results are presented in tables 39 and 40 as accumulative statistics for the vehicle groups on different lanes and in figures 50 and 51 as cumulative load distributions on different lanes.

*Table 39. Accumulative statistics for the vehicle groups lane 1, towards Oulu.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 145 | 77 | 1 304 | 314 | 115 | 46 | **2 001** |
| Speed (ave.)¹ | 70,79 | 77,77 | 83,28 | 77,3 | 76,67 | 87,46 | **80,94** |
| GVW average | 14,24 | 17,94 | 39,77 | 31,03 | 13,97 | 56,33 | **34,6** |
| Total GVW² | 2 064,8 | 1 381,38 | 51 860,08 | 9 743,42 | 1 606,55 | 2 591,18 | **69 234,6** |
| ESAL (Ave.)³ | 0,45 | 0,79 | 2,32 | 1,22 | 0,54 | 3,00 | **1,89** |

*Table 40. Accumulative statistics for the vehicle groups lane 2, towards Jyväskylä.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 143 | 136 | 1 844 | 465 | 195 | 44 | **2 827** |
| **Speed (ave.)¹** | 70,39 | 80,59 | 78,25 | 73,99 | 78,26 | 76,53 | **77,24** |
| **GVW average** | 13,7 | 18,84 | 34,38 | 30,65 | 14,5 | 53,82 | **30,9** |
| **Total GVW²** | 1 959,1 | 2 562,24 | 63 396,72 | 14 252,25 | 2 827,5 | 2 368,08 | **87 354,3** |
| **ESAL (Ave.)³** | 0,39 | 1,3 | 1,63 | 1,21 | 0,79 | 1,59 | **1,44** |

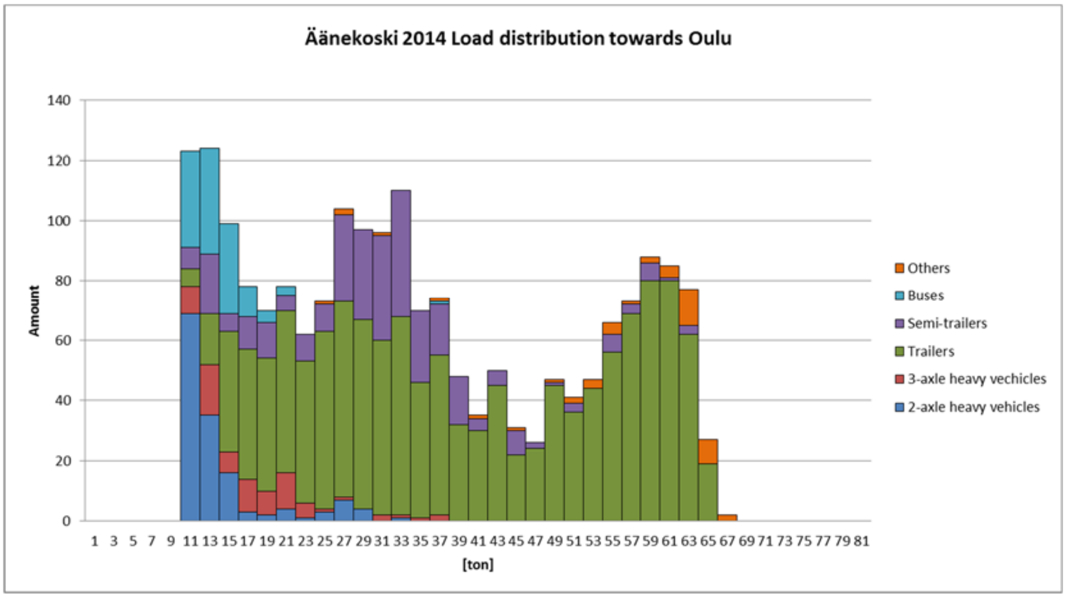



*Figure 50. Load distribution cumulative, towards Oulu.*

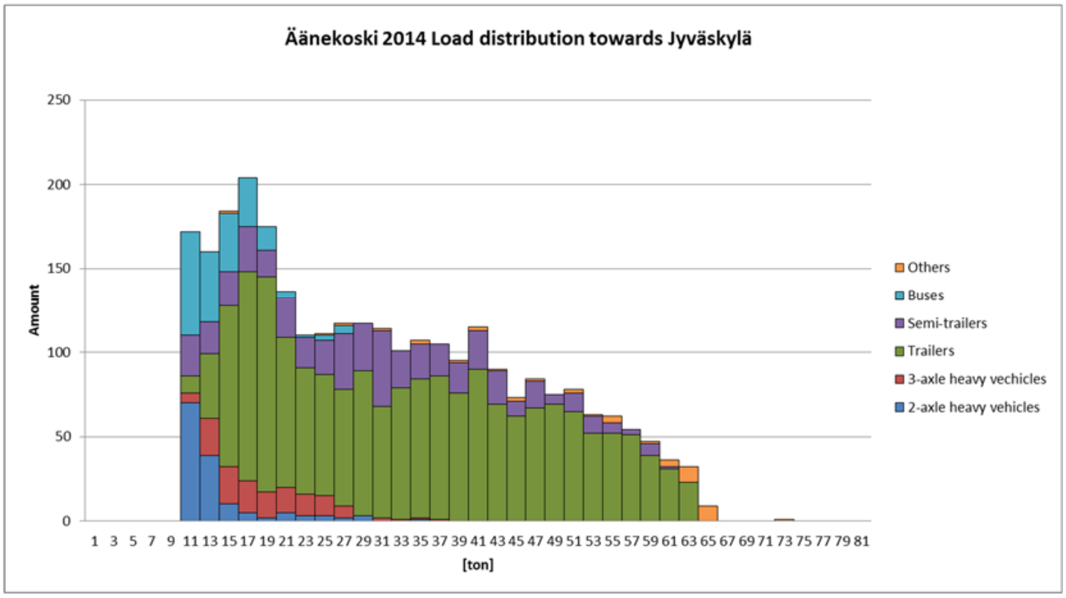



*Figure 51. Load distribution cumulative, towards Jyväskylä.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From figure 52 and table 41, it can be seen that the percentage of all overloaded vehicles is nearly 8% in total. That is, with overloads on (all) gross weight, axles or both.

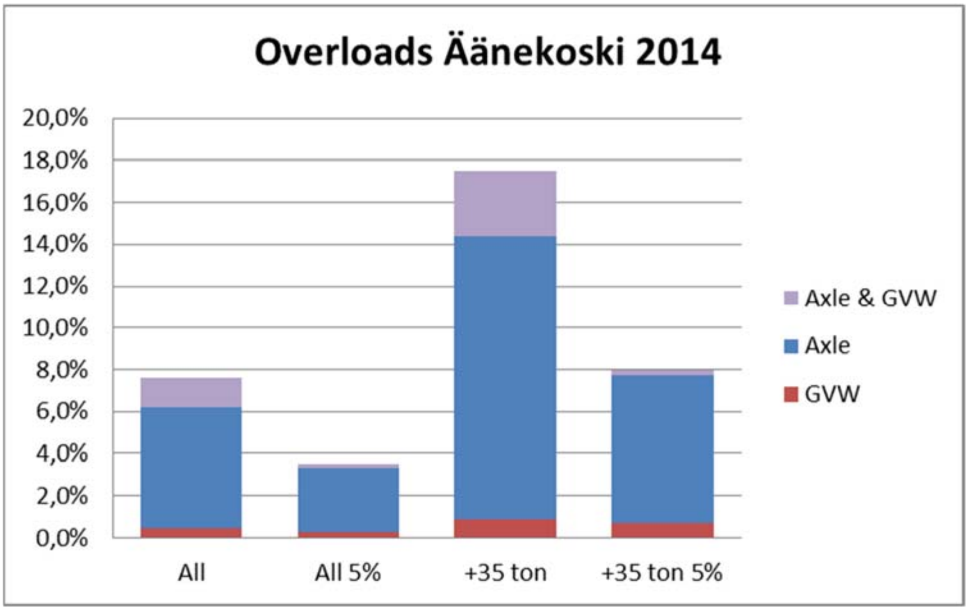



*Figure 52. Overload results from Äänekoski bridge measurement 2014.*

*Table 41. Overload results from Äänekoski bridge measurement 2014.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 5,8% | 0,4% | 1,4% | **7,6%** |
| **All 5%** | 3,0% | 0,3% | 0,2% | **3,5%** |
| **+35t** | 13,5% | 0,9% | 3,1% | **17,5%** |
| **+35t +5%** | 7,0% | 0,7% | 0,3% | **8,0%** |

### 3.4.3 Measurement 2015

The weather during the assembly of the system was quite fine. Temperatures ranged from 8 degrees (night time) to 14 degrees in the day.

The system was mounted and calibrated on 10th September 2015, and the dismounting and re-calibration took place on the 22th September 2015.

Measurement results are presented in tables 42 and 43 as accumulative statistics for the vehicle groups on different lanes and in figures 53 and 54 as cumulative load distributions on different lanes.

*Table 42. Accumulative statistics for the vehicle groups lane 2, towards Oulu.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 124 | 115 | 1 677 | 399 | 192 | 32 | **2 539** |
| **Speed (ave.)[1]** | 75,14 | 84,42 | 84,93 | 79,89 | 80,11 | 88,41 | **83,32** |
| **GVW average** | 12,99 | 21,15 | 43,92 | 32,97 | 15,50 | 57,47 | **37,68** |
| **Total GVW[2]** | 1 610,76 | 2 432,25 | 73 653,84 | 13 155,03 | 2 976,00 | 1 839,04 | **95 669,52** |
| **ESAL (Ave.)[3]** | 0,67 | 2,01 | 3,24 | 1,65 | 0,96 | 3,37 | **2,64** |

*Table 43. Accumulative statistics for the vehicle groups lane 1, towards Jyväskylä.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 61 | 99 | 2 023 | 402 | 257 | 24 | **2 866** |
| **Speed (ave.)[1]** | 74,52 | 84,93 | 80,83 | 77,62 | 81,96 | 79,97 | **80,48** |
| **GVW average** | 12,44 | 20,98 | 39,41 | 29,61 | 15,78 | 59,90 | **34,87** |
| **Total GVW[2]** | 758,84 | 2 077,02 | 79 726,43 | 11 903,22 | 4 055,45 | 1 437,6 | **99 937,42** |
| **ESAL (Ave.)[3]** | 0,55 | 1,75 | 2,47 | 1,23 | 1,00 | 3,53 | **2,11** |

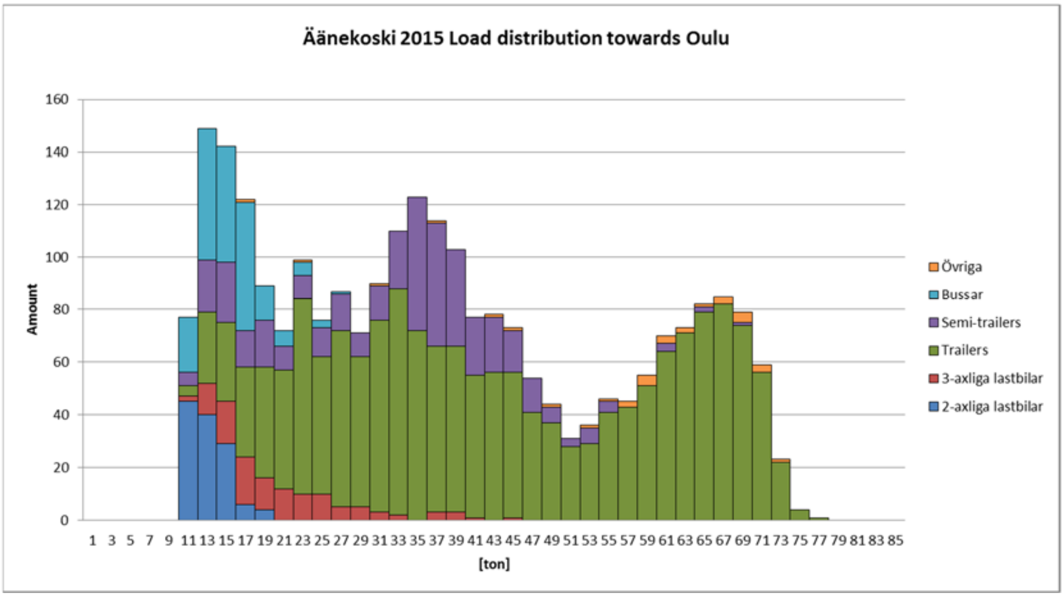



*Figure 53.* *Load distribution cumulative, towards Oulu.*

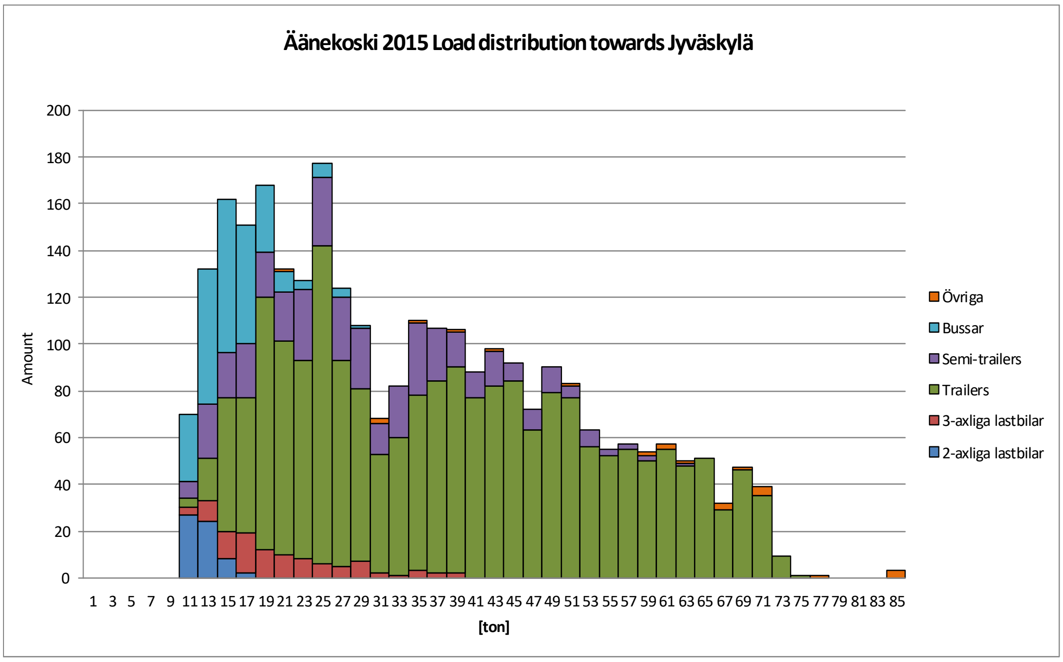



*Figure 54.* *Load distribution cumulative, towards Jyväskylä.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From figure 55 and table 44, it can be seen that the percentage of all overloaded vehicles is nearly 18% in total. That is, with overloads on (all) gross weight, axles or both.

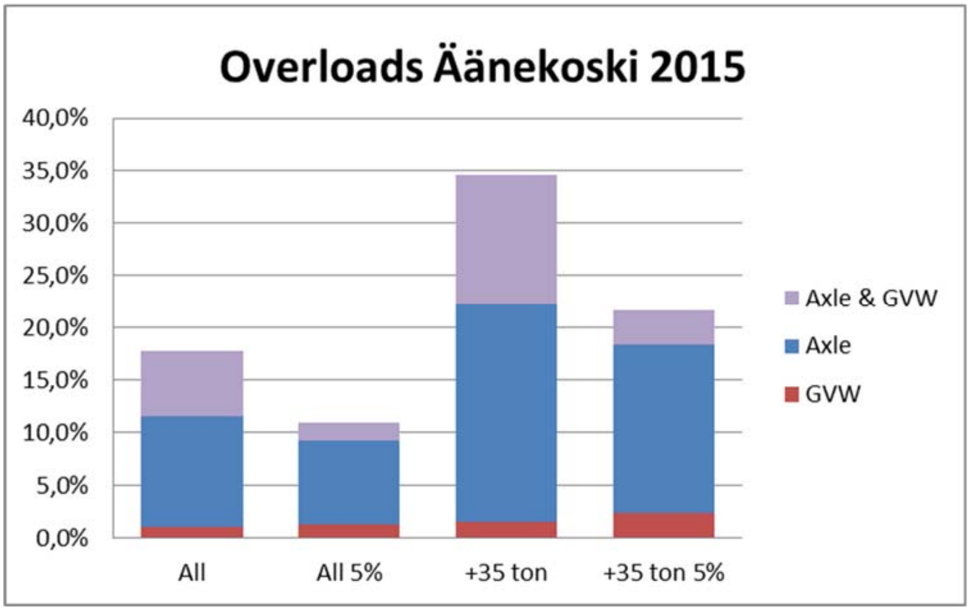



*Figure 55. Overload results from Äänekoski bridge measurement 2015.*

*Table 44. Overload results from Äänekoski bridge measurement 2015.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 10,4% | 1,1% | 6,2% | **17,7%** |
| **All 5%** | 7,9% | 1,3% | 1,7% | **10,9%** |
| **+35t** | 20,8% | 1,5% | 12,3% | **34,6%** |
| **+35t +5%** | 16,0% | 2,3% | 3,3% | **21,6%** |

### 3.4.4 Measurement 2016

Measurement results are presented in tables 45 and 46 as accumulative statistics for the vehicle groups on different lanes and in figures 57 and 58 as cumulative load distributions on different lanes.

High asymmetry of traffic loading where lane 1 is much lighter – empty trucks. Structure of the traffic is expected, with higher average GVW (trucks are, when loaded, loaded to the max or just slightly over). Looking at the structure of overloading – vehicles are, comparing to last year's data, less overloaded but the amount of them is higher. Significant amount of class 140 1-2-3-2-3 vehicles with 90t. Also there are a number of vehicles with driving axles over 13t. An issue for discussion are lifting axles – a lot of them are hardly touching the surface of the road.

*Figure 56. Calibration vehicle Äänekoski 2016.*

*Table 45. Accumulative statistics for the vehicle groups lane 2, towards Oulu.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 50 | 58 | 1 552 | 442 | 204 | 79 | **2 389** |
| **Speed (ave.)¹** | 79,1 | 79,74 | 81,38 | 77,78 | 82,72 | 79,54 | **80,65** |
| **GVW average** | 14,35 | 24,67 | 57,26 | 39,35 | 19,64 | 62,89 | **49,13** |
| **Total GVW²** | 717,5 | 1 430,86 | 88 867,52 | 17 392,7 | 4 006,56 | 4 968,31 | **117 371,57** |
| **ESAL (Ave.)³** | 1,18 | 1,21 | 3,2 | 1,98 | 1,65 | 3,78 | **2,77** |

*Table 46. Accumulative statistics for the vehicle groups lane 1, towards Jyväskylä.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 118 | 95 | 1 933 | 492 | 200 | 70 | **2 911** |
| **Speed (ave.)¹** | 69,51 | 74,89 | 74,89 | 71,89 | 77,41 | 72,47 | **74,27** |
| **GVW average** | 13,25 | 21,87 | 39,71 | 31,17 | 17,55 | 55,55 | **35,43** |
| **Total GVW²** | 1 563,5 | 2 077,65 | 76 759,43 | 15 335,64 | 3 510 | 3 888,5 | **103 136,73** |
| **ESAL (Ave.)³** | 0,74 | 0,89 | 1,28 | 0,87 | 0,68 | 2,3 | **1,16** |

From table 47, it can be seen that there has been a marked increase in the average GVW since the introduction of the new Finlex regulations.

*Table 47. Average GVW per direction, comparison per year.*

| Average GVW per direction, Increase Comparison | | | | | | |
|---|---|---|---|---|---|---|
| **Direction** | **year 2014** | **year 2015** | **year 2016** | **2014–2015 Increase(%)** | **2015–2016 Increase(%)** | **2014–2016 Increase(%)** |
| Oulu | 34,60 t | 37,68 t | 49,13 t | 8,2% | 23,3% | 29,6% |
| Jyväskylä | 30,90 t | 34,87 t | 35,43 t | 11,4% | 1,6% | 12,8% |

This road section has proven that the greater majority of heavy vehicles is in the northbound direction, towards Oulu. Together with the vehicle analysis from Olhava (shown later in this document) it is evident that haulers are now introducing and using vehicles with more axles and greater loading.

A 29% increase is indeed significant, but if the vehicle is correctly loaded, this extra loading is offset by reduced number of journeys and environmental impact through reduction of overall emissions. Case studies and models have shown this to be correct, although the projected differences are small when considering the extra requirements from the powertrains to move the heavier loads.

Further studies at the same specific points, will indicate future trending and a stabilization plateau.

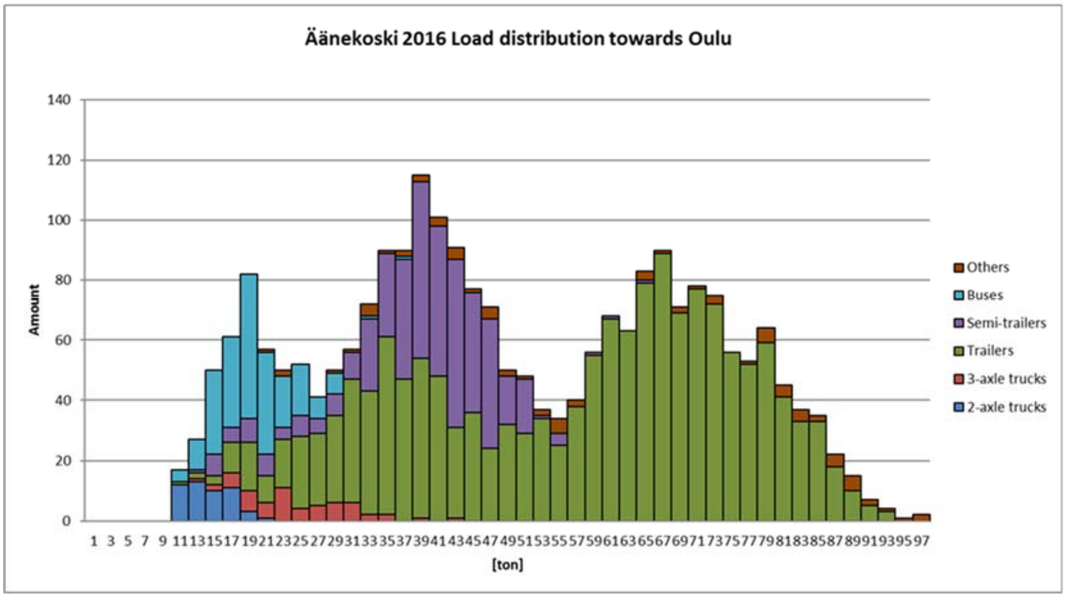



*Figure 57. Load distribution cumulative, towards Oulu.*

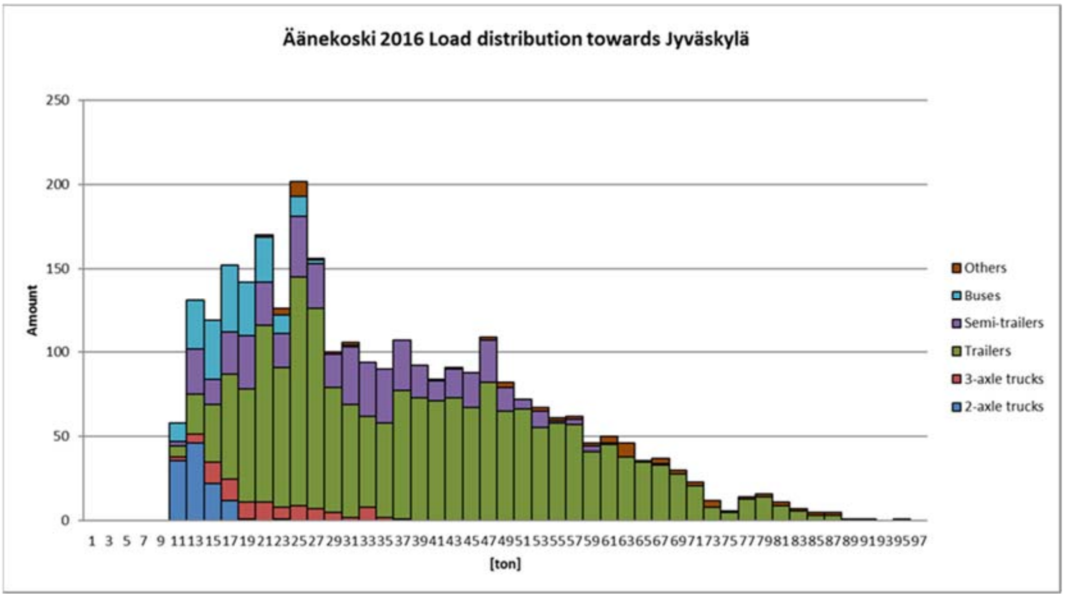



*Figure 58. Load distribution cumulative, towards Jyväskylä.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From figure 59 and table 48, it can be seen that the percentage of all overloaded vehicles is 38% in total. That is, with overloads on (all) gross weight, axles or both.

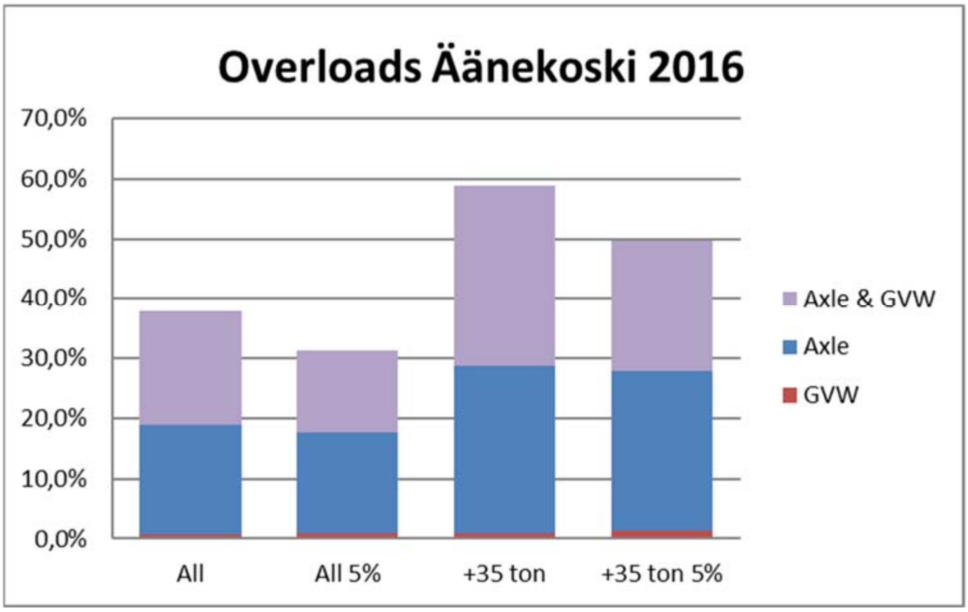



*Figure 59. Overload results from Äänekoski bridge measurement 2016.*

*Table 48. Overload results from Äänekoski bridge measurement 2016.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 18,1% | 0,7% | 19,1% | **38,0%** |
| **All 5%** | 16,9% | 0,9% | 13,7% | **31,4%** |
| **+35t** | 27,9% | 0,9% | 30,2% | **59,0%** |
| **+35t +5%** | 26,6% | 1,4% | 21,7% | **49,7%** |

# 3.5 Ring road III, Westbound 2014, 2015 and 2017

### 3.5.1 Overview, Ring road III, Westbound

The site is situated in Espoo. Classified as the Ring Road III (Kehä III) it also carries roads E18 and Road 50 (linking to Highway 1), The Easterly direction carries trunk traffic towards Vantaa, Helsinki Airport and beyond to the Russian border. The **Westerly direction** carries traffic from these destinations towards Espoo and onwards to Turku on the western coast. This is a heavily laden road and traffic volumes are extreme during peak periods.

*Table 49. Bridge data of Ring road III bridge, westbound.*

| | |
|---|---|
| Bridge name: | Ring road III, Westbound (Vanhankartanon alikulkukäytävä) |
| Road/Location: | Ring road III, road 50, Espoo |
| Lanes: | 2 + 2 |
| Measured direction: | Westbound, 2 lanes |
| Bridge Id: | U-1553 |
| Bridge type: | |
| Coordinate lat/long: | 60.2659, 24.74788 |



Source: Google.com

*Table 50. Measured traffic data from Ring road III bridge, westbound 2014, 2015 and 2017.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| **Results** | **ESAL** | **# Per day** | **GVW** | **Weight** | **Amount** | **Axle** | **GVW** | **Both** |
| 2014 | 0,90 | 1 408 | 26,73t | 263 380 t | 9 855 | 25,9% | 1,2% | 6,6% |
| 2015 | 0,74 | 1 507 | 24,29 t | 256 260 t | 10 548 | 27,0% | 1,4% | 7,9% |
| 2017 | 0,78 | 1 603 | 26,33 t | 295 434 t | 11 222 | 20,2% | 1,6% | 8,1% |

*Figure 60. Ring road III bridge from south (Vanhankartanon alikulkukäytävä).*

### 3.5.2 Measurement 2014

The weather over the period was reasonable with some precipitation, especially around the mid-summer period. The temperature range was between +15°C to +23°C.

The system was installed on 18th June 2014 and dismantled on 2nd July 2014, the analysis period was taken between 23rd June and 29th June due to the effect on traffic flow caused by the midsummer holiday.

The Westbound direction has higher average ESAL value due to the more loaded vehicles than in the Easterly direction. It is the class 105 which is mostly overloaded (1-3-1-2). The structure of the traffic is slightly different from the Eastbound direction (more loaded vehicles, class 40 (1-1)).

Comparing the average GVW of the vehicles, the Westbound direction is 5t higher, mostly because of the heavy loaded vehicles in types 2-2-1-3, 2-3-1-3, 2-2-2-3, 1-2-3-3, 1-3-3-3.

Looking at the GVW the Eastbound direction has less total vehicles, and less vehicles with higher weights, the Westbound direction shows increases in the frequencies between 50-65t.

As this measurement is on a two-lane highway, both lanes have been analyzed. The majority of the heavier traffic is driving in lane 1, identified by the distributions in the coming diagrams below, where lane 2 is carrying mainly 2/3 axle trucks and busses.

Measurement results are presented in tables 51 and 52 as accumulative statistics for the vehicle groups on different lanes and in figures 61 and 62 as cumulative load distributions on different lanes.

*Table 51. Accumulative statistics for the vehicle groups Westbound, Lane 1.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 1 213 | 1 701 | 3 837 | 1 974 | 924 | 54 | **9 703** |
| **Speed (ave.)¹** | 82,62 | 84,37 | 82,78 | 83,09 | 84,07 | 81,2 | **83,21** |
| **GVW average** | 13,03 | 21,77 | 35,43 | 28,09 | 13,6 | 51,73 | **26,75** |
| **Total GVW²** | 15 805,39 | 37 030,77 | 135 944,91 | 55 449,66 | 12 566,4 | 2 793,42 | **259 555,25** |
| **ESAL (Ave.)³** | 0,55 | 0,75 | 1,2 | 0,83 | 0,44 | 1,82 | **0,9** |

*Table 52. Accumulative statistics for the vehicle groups Westbound, Lane 2.*

| Vehicle group | 2-axled laden trucks | 3-axled laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 26 | 13 | 43 | 26 | 43 | 1 | **152** |
| **Speed (ave.)¹** | 90,73 | 88,77 | 93,87 | 92,9 | 97,68 | 92,16 | **93,8** |
| **GVW average** | 14,98 | 20,1 | 34,47 | 36,3 | 14,97 | 63,66 | **24,9** |
| **Total GVW²** | 389,48 | 261,3 | 1 482,21 | 943,8 | 643,71 | 63,66 | **3 784,8** |
| **ESAL (Ave.)³** | 0,96 | 0,52 | 1,3 | 1,48 | 0,74 | 2,68 | **1,06** |

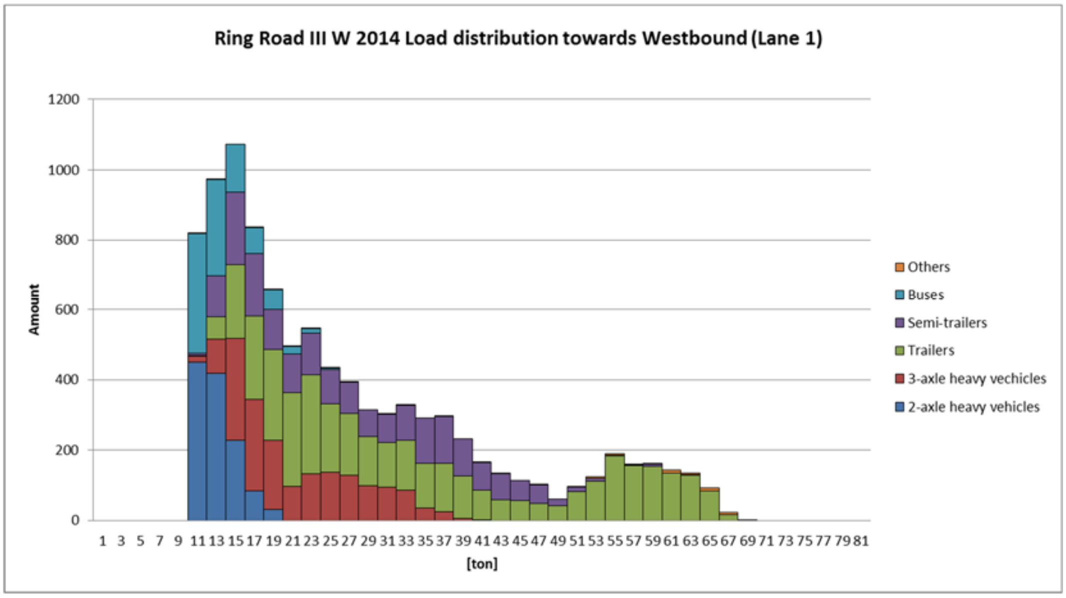



*Figure 61. Load distribution cumulative, Westbound Lane 1.*

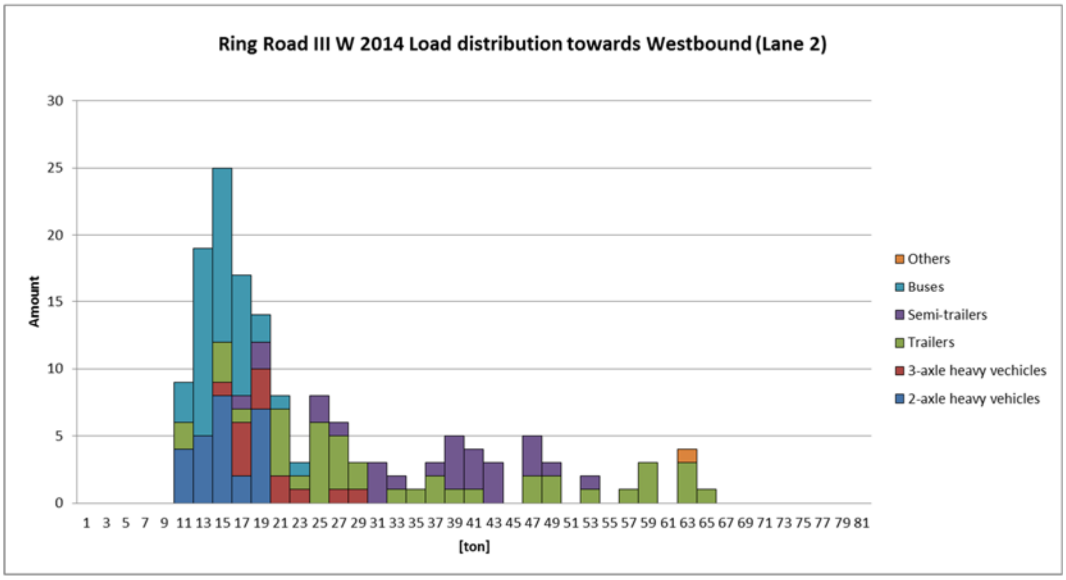



*Figure 62. Load distribution cumulative, Westbound Lane 2. Note that the Lane 2 (fast lane) has a lot fewer vehicle amount than in Lane 1.*

**Overload results**

Overloads presented in this section are for vehicles in both lanes. From figure 63 and table 53, it can be seen that the percentage of **all** overloaded vehicles is just above 16% in total. That is, with overloads on (all) gross weight, axles or both.

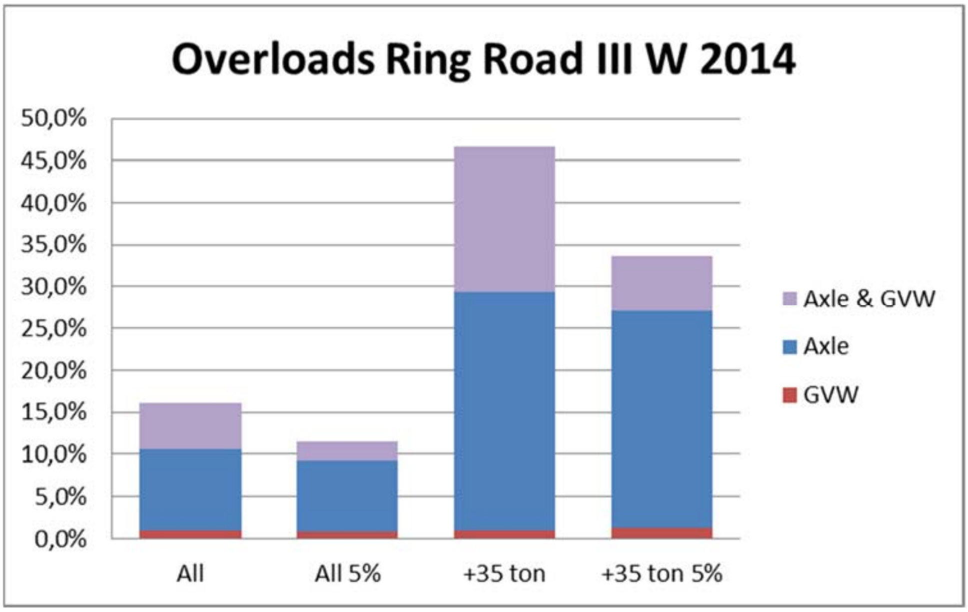



*Figure 63. Overload results from Ring road III bridge (westbound) measurement 2014.*

*Table 53. Overload results from Ring road III bridge (westbound) measurement 2014.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 9,6% | 1,0% | 5,5% | **16,2%** |
| **All 5%** | 8,5% | 0,8% | 2,2% | **11,4%** |
| **+35t** | 28,4% | 0,9% | 17,3% | **46,7%** |
| **+35t +5%** | 25,9% | 1,2% | 6,6% | **33,7%** |

### 3.5.3 Measurement 2015

The weather over the period was reasonable with some light precipitation. The temperature range was between +8°C (night time) to +15°C.

The system was installed on 23rd September 2015 and calibrated on 24th September. Calibrations showed a very high accuracy level of A5 across all parameters. The system was re-calibrated on 1st October 2015 and dismantled on the same day. The analysis period was taken between 24th September and 30th September.

As this measurement is on a two-lane highway, both lanes have been analyzed. The majority of the heavier traffic is driving in lane 1, identified by the distributions in the coming diagrams below, where lane 2 is carrying mainly 2/3 axle trucks and busses.

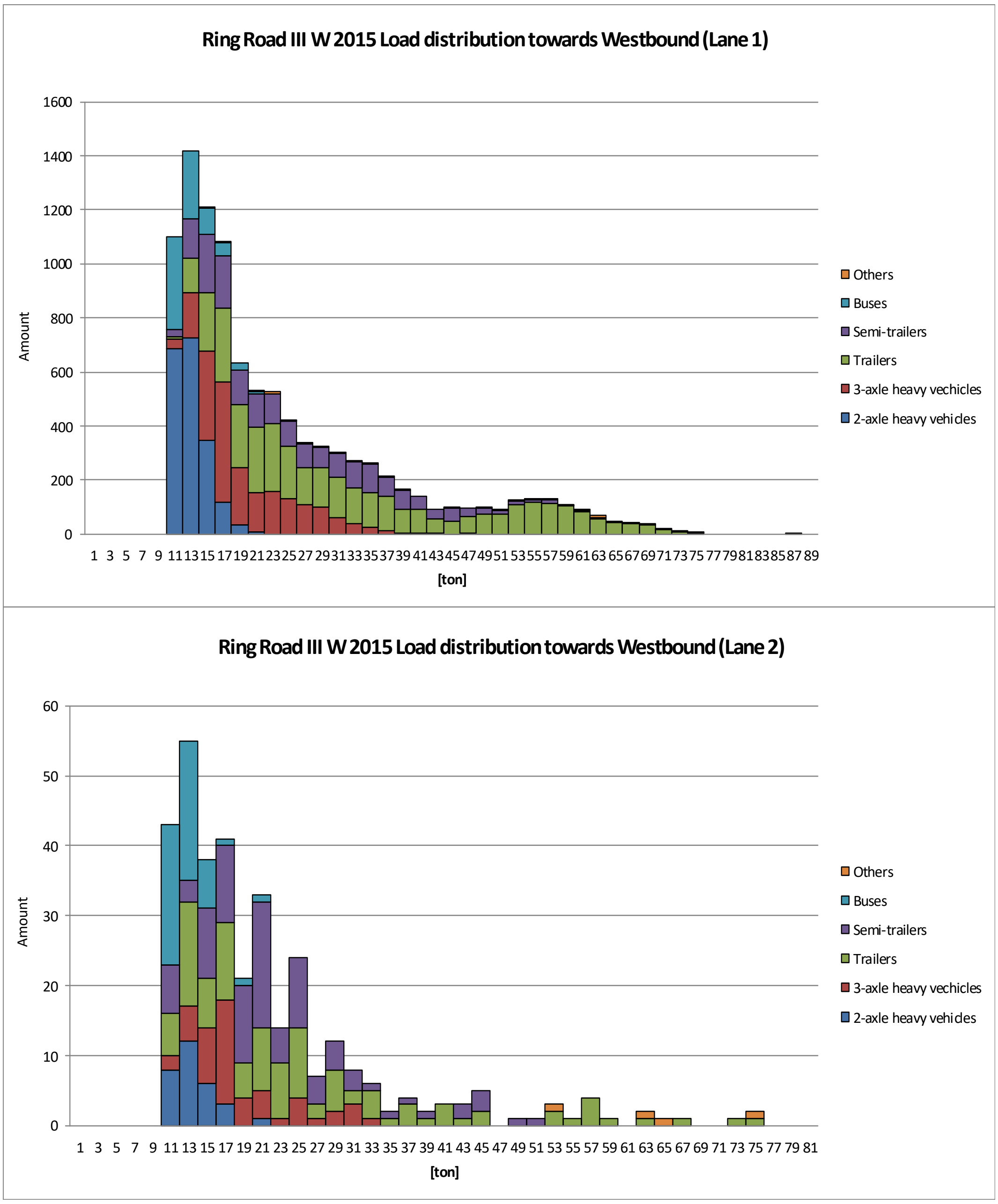
Measurement results are presented in tables 54 and 55 as accumulative statistics for the vehicle groups on different lanes and in figures 64 and 65 as cumulative load distributions on different lanes.

*Table 54. Accumulative statistics for the vehicle groups Westbound, Lane 1.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 1 920 | 1 989 | 3 578 | 1 863 | 782 | 77 | **10 209** |
| **Speed (ave.)[1]** | 78,22 | 79,79 | 78,18 | 79,00 | 80,16 | 76,94 | **78,79** |
| **GVW average** | 12,96 | 20,20 | 33,79 | 26,30 | 12,93 | 50,06 | **24,38** |
| **Total GVW[2]** | 24 883,20 | 40 177,80 | 120 900,62 | 48 996,90 | 10 111,26 | 3 854,62 | **248 895,42** |
| **ESAL (Ave.)[3]** | 0,52 | 0,59 | 1,02 | 0,71 | 0,40 | 2,35 | **0,75** |

*Table 55. Accumulative statistics for the vehicle groups Westbound, Lane 2.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 30 | 50 | 108 | 97 | 50 | 4 | **339** |
| **Speed (ave.)[1]** | 91,22 | 94,61 | 95,59 | 100,96 | 96,92 | 89,65 | **96,72** |
| **GVW average** | 13,62 | 19,13 | 26,49 | 22,61 | 12,95 | 64,14 | **21,6** |
| **Total GVW[2]** | 408,60 | 956,50 | 2 860,92 | 2 193,17 | 647,50 | 256,56 | **7 322,40** |
| **ESAL (Ave.)[3]** | 0,59 | 0,48 | 0,61 | 0,40 | 0,45 | 2,74 | **0,53** |




*Figures 65. Load distribution cumulative, Westbound Lane 2. Note that the Lane 2 (fast lane) has a lot fewer vehicle amount than in Lane 1.*

**Overload results**

Overloads presented in this section are for vehicles in both lanes. From figure 66 and table 56, it can be seen that the percentage of **all** overloaded vehicles is just above 12% in total. That is, with overloads on (all) gross weight, axles or both.

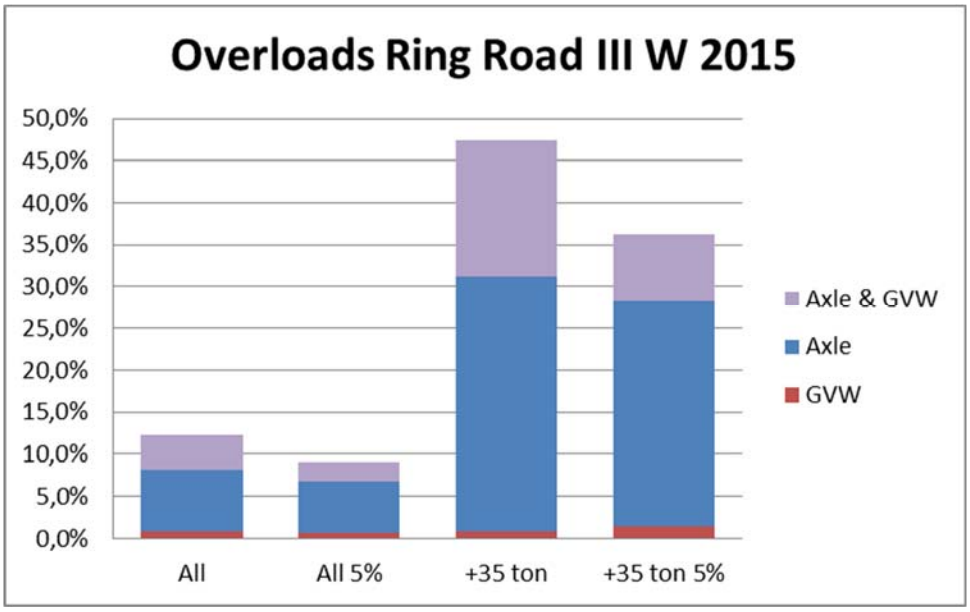



*Figure 6 6. Overload results from Ring road III bridge (westbound) measurement 2015.*

*Table 56. Overload results from Ring road III bridge (westbound) measurement 2015.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 7,3% | 0,9% | 4,2% | **12,3%** |
| **All 5%** | 6,1% | 0,7% | 2,2% | **9,0%** |
| **+35t** | 30,4% | 0,8% | 16,2% | **47,4%** |
| **+35t +5%** | 27,0% | 1,4% | 7,9% | **36,2%** |

### 3.5.4 Measurement 2017

The weather over the period was mostly overcast with also some rain/clear and sunny. The temperature range was between +7°C to +10°C.

The system was installed on 3rd October and calibrated on 4th October. The system was re-calibrated on 17th October and dismantled the next day. The analysis period was taken between 4th October and 10th October.

As this measurement is on a two-lane highway, both lanes have been analyzed. The majority of the heavier traffic is driving in lane 1, identified by the distributions in the coming diagrams below.

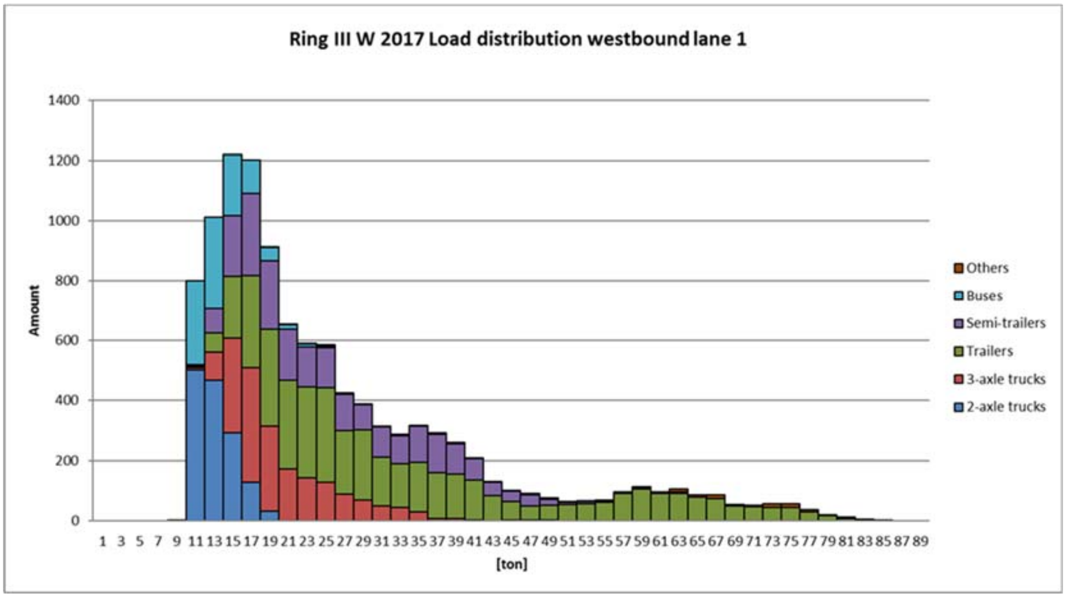
Measurement results are presented in tables 57 and 58 as accumulative statistics for the vehicle groups on different lanes and in figures 67 and 68 as cumulative load distributions on different lanes.

*Table 57. Accumulative statistics for the vehicle groups Westbound, Lane 1.*

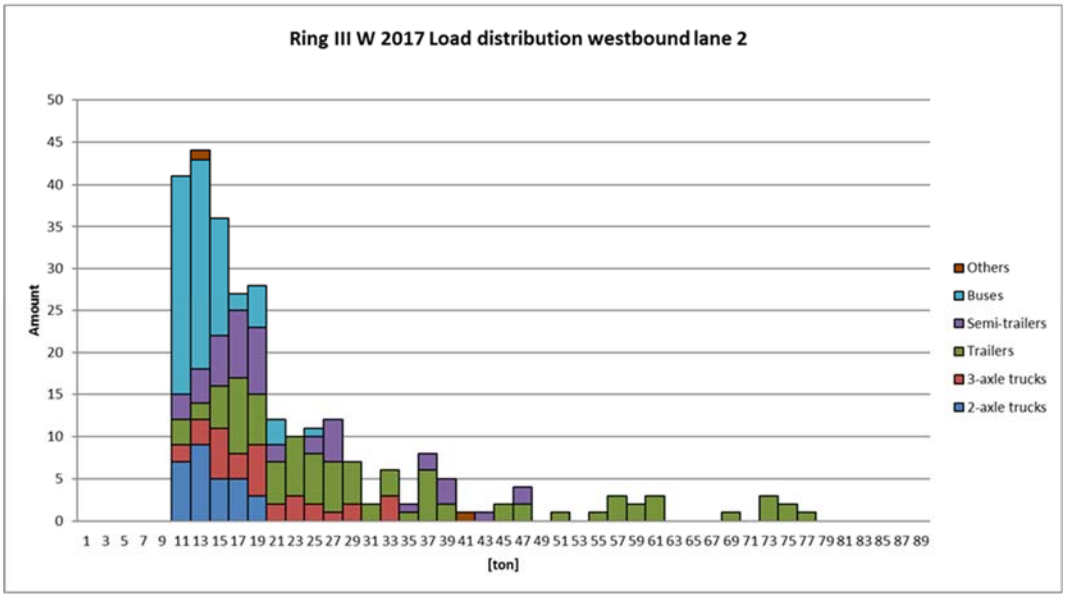
| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 1 420 | 1 837 | 4 358 | 2 209 | 976 | 146 | **10 964** |
| **Speed (ave.)[1]** | 80,45 | 81,92 | 80,83 | 81,36 | 82,27 | 80,46 | **81,19** |
| **GVW average** | 13,15 | 20,54 | 34,95 | 26,53 | 13,83 | 58,25 | **26,39** |
| **Total GVW[2]** | 18 673 | 37 731,98 | 152 312,1 | 58 604,77 | 13 498,08 | 8 504,5 | **289 339,96** |
| **ESAL (Ave.)[3]** | 0,49 | 0,61 | 1,04 | 0,69 | 0,42 | 2,46 | **0,79** |

*Table 58. Accumulative statistics for the vehicle groups Westbound, Lane 2.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 29 | 33 | 89 | 47 | 76 | 2 | **278** |
| **Speed (ave.)[1]** | 89,93 | 87,34 | 89,09 | 90,02 | 96,66 | 100,88 | **91,26** |
| **GVW average** | 14,16 | 20,01 | 32,6 | 22,33 | 13,62 | 27,54 | **21,99** |
| **Total GVW[2]** | 410,64 | 660,33 | 2 901,4 | 1 049,51 | 1 035,12 | 55,08 | **6 113,22** |
| **ESAL (Ave.)[3]** | 0,73 | 0,52 | 0,91 | 0,55 | 0,44 | 0,58 | **0,65** |




*Figures 67. Load distribution cumulative, Westbound Lane 1:*




*Figures 68. Load distribution cumulative, Westbound Lane 2. Note that the Lane 2 (fast lane) has a lot fewer vehicle amount than in Lane 1.*

**Overload results**

Overloads presented in this section are for vehicles in both lanes. From figure 69 and table 59, it can be seen that the percentage of **all** overloaded vehicles is just above 11% in total. That is, with overloads on (all) gross weight, axles or both.

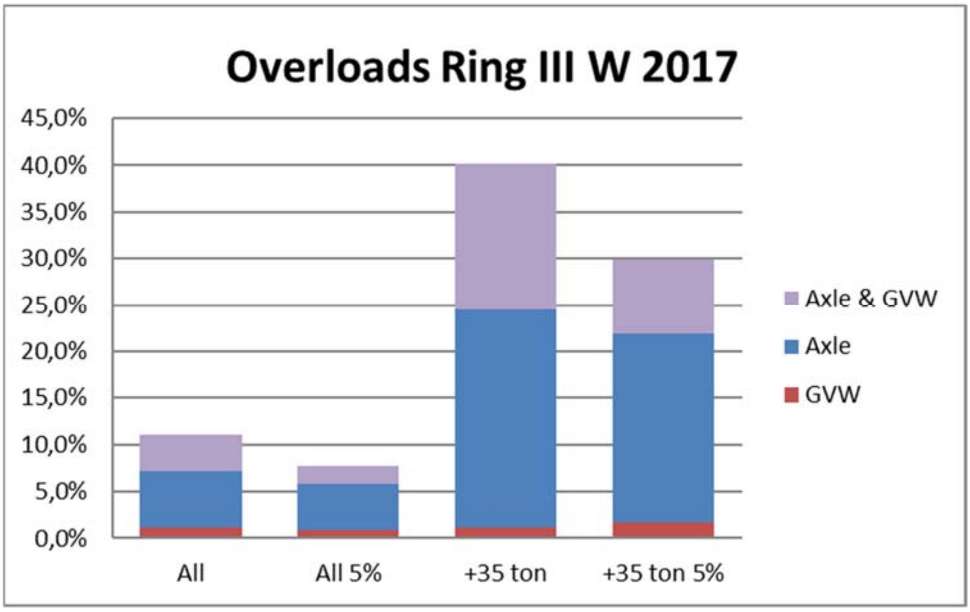



*Figure 69.* *Overload results from Ring road III bridge (westbound) measurement 2015.*

*Table 59.* *Overload results from Ring road III bridge (westbound) measurement 2015.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 6,0% | 1,2% | 3,9% | 11,1% |
| **All 5%** | 4,9% | 0,8% | 2,0% | 7,8% |
| **+35t** | 23,4% | 1,2% | 15,7% | 40,2% |
| **+35t +5%** | 20,2% | 1,6% | 8,1% | 30,0% |

# 3.6 Ring road III, Eastbound 2014, 2015 and 2017

### 3.6.1 Overview, Ring road III, Eastbound

The site is situated in Espoo. Classified as the Ring Road III (Kehä III) it also carries roads E18 and Road 50 (linking to Road 1), The **Easterly direction** carries trunk traffic towards Vantaa, Helsinki Airport and beyond to the Russian border. The westerly direction carries traffic from these destinations towards Espoo and onwards to Turku on the western coast. This is a heavily laden road and traffic volumes are extreme during peak periods.

*Table 60. Bridge data of Ring road III bridge, eastbound.*

| | |
|---|---|
| Bridge name: | Ring road III, Eastbound (Vanhankartanon alikulkukäytävä) |
| Road/Location: | Ring road III, road 50, Espoo |
| Lanes: | 2 + 2 |
| Measured direction: | Eastbound, 2 lanes |
| Bridge Id: | U-1553 |
| Bridge type: | |
| Coordinate lat/long: | 60.26579, 24.74798 |



Source: Google.com

*Table 61. Measured traffic data from Ring road III bridge, eastbound 2014, 2015 and 2017.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| **Results** | **ESAL** | **# Per day** | **GVW** | **Weight** | **Amount** | **Axle** | **GVW** | **Both** |
| 2014 | 0,57 | 1 541 | 22,56 t | 243 404 t | 10 788 | 8,8% | 1,1% | 1,5% |
| 2015 | 0,66 | 1 706 | 22,56 t | 287 347 t | 11 941 | 15,9% | 1,3% | 2,0% |
| 2017 | 0,94 | 1 855 | 27,20 t | 353 167 t | 12 983 | 14,1% | 4,0% | 10,6% |

### 3.6.2 Measurement 2014

The weather over the period was reasonable with some precipitation, especially around the mid-summer period. The temperature range was between +15°C to +23°C.

The system was installed on 18th June 2014 and dismantled on 2nd July 2014, the analysis period was taken between 23rd June and 29th June due to the effect on traffic flow caused by the midsummer holiday.

The measurement at this site shows a predominance of 2/3 axle vehicles, typical of local industry delivery and trailer type trucks with an axle pattern of 113 or 123 commonly seen on trunk roads as long haulage vehicles.

As this measurement is on a two-lane highway, both lanes have been analyzed. The majority of the heavier traffic is driving in lane 1, identified by the distributions in the coming diagrams below, where lane 2 is carrying mainly 2/3 axle trucks and busses.

*Figure 70. Calibration vehicle Ring road III 2014.*

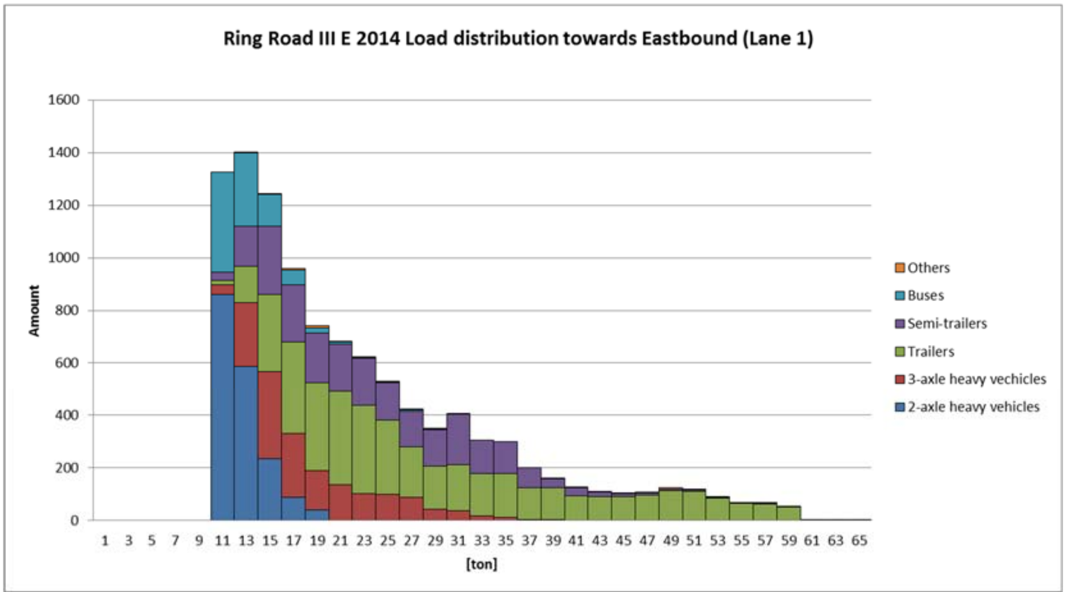
Measurement results are presented in tables 62 and 63 as accumulative statistics for the vehicle groups on different lanes and in figures 71 and 72 as cumulative load distributions on different lanes.

*Table 62. Accumulative statistics for the vehicle groups Eastbound, Lane 1.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 1 808 | 1 552 | 4 074 | 2 263 | 878 | 51 | **10 626** |
| **Speed (ave.)[1]** | 82,47 | 85,85 | 82,84 | 83,75 | 84,67 | 85,71 | **83,58** |
| **GVW average** | 12,58 | 18,95 | 29,34 | 24,28 | 12,95 | 32 | **22,55** |
| **Total GVW[2]** | 22 744,64 | 29 410,40 | 119 531,16 | 54 945,64 | 11 370,10 | 1 632,00 | **239 616,30** |
| **ESAL (Ave.)[3]** | 0,48 | 0,47 | 0,69 | 0,51 | 0,43 | 0,79 | **0,56** |

*Table 63. Accumulative statistics for the vehicle groups Eastbound, Lane 2.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 19 | 21 | 54 | 23 | 45 | 0 | **162** |
| Speed (ave.)¹ | 92,57 | 93,88 | 94,87 | 100,4 | 98,56 | 0 | **96,28** |
| GVW average | 15,16 | 20,77 | 30,89 | 31,96 | 14,87 | 0 | **23,44** |
| Total GVW² | 288,04 | 436,17 | 1 668,06 | 735,08 | 669,15 | 0,00 | **3 797,28** |
| ESAL (Ave.)³ | 0,94 | 0,65 | 1,06 | 1,14 | 0,87 | 0 | **0,95** |



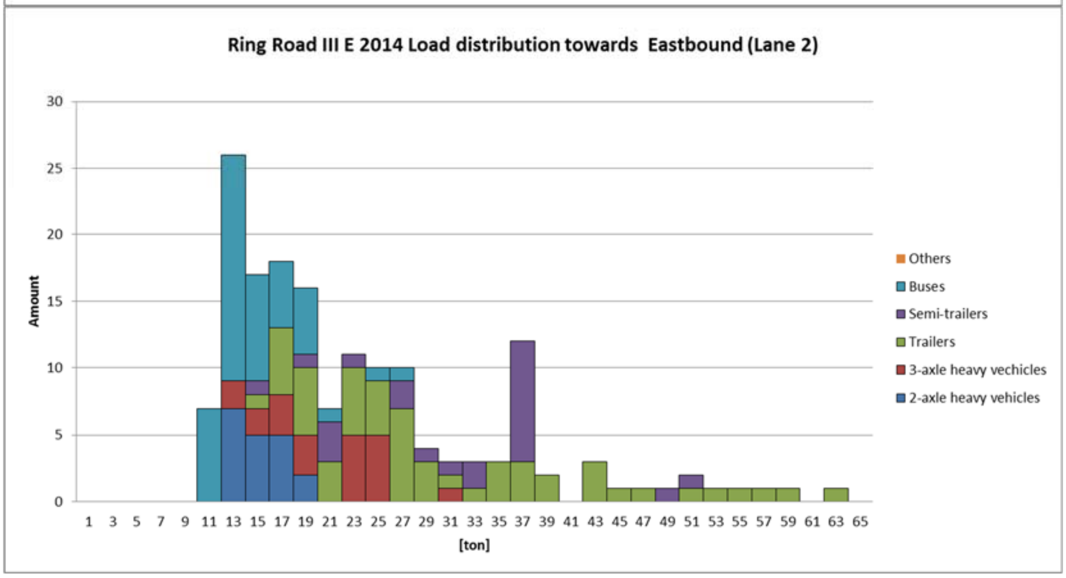




*Figure 72. Load distribution cumulative, Eastbound Lane 2. Note that the Lane 2 (fast lane) has a lot fewer vehicle amount than in Lane 1.*

**Overload results**

Overloads presented in this section are for vehicles in both lanes. From figure 73 and table 64, it can be seen that the percentage of **all** overloaded vehicles is 4,7% in total. That is, with overloads on (all) gross weight, axles or both.

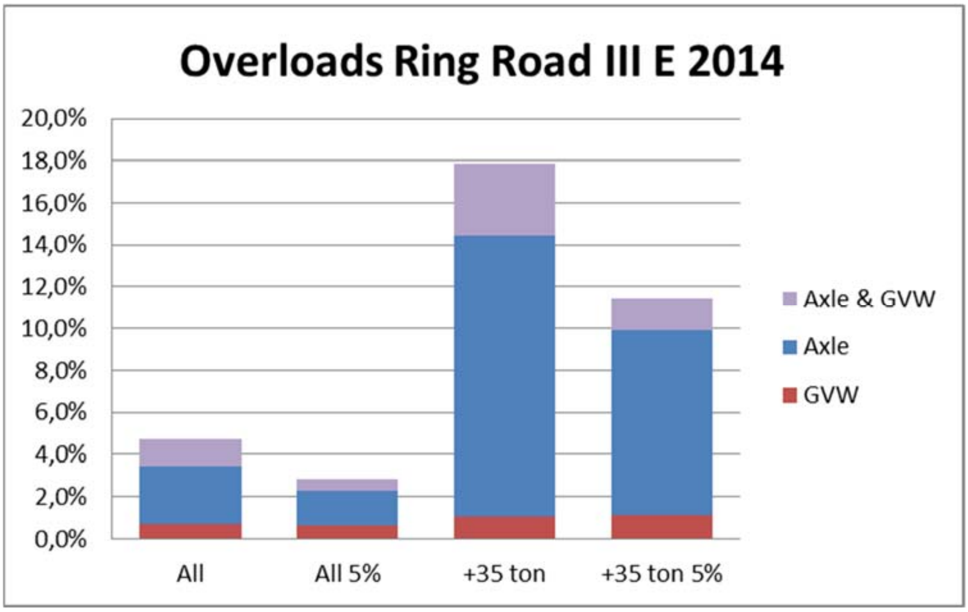



*Figure 73. Overload results from Ring road III bridge (westbound) measurement 2014.*

*Table 64. Overload results from Ring road III bridge (westbound) measurement 2014.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 2,7% | 0,7% | 1,3% | **4,7%** |
| **All 5%** | 1,7% | 0,6% | 0,5% | **2,8%** |
| **+35t** | 13,4% | 1,1% | 3,4% | **17,9%** |
| **+35t +5%** | 8,8% | 1,1% | 1,5% | **11,5%** |

### 3.6.3 Measurement 2015

The weather over the period was reasonable with some light precipitation. The temperature range was between +8°C (night time) to +15°C.

The system was installed on 23rd September 2015 and calibrated on 24th September. Calibrations showed a very high accuracy level of A5 across all parameters. The system was re-calibrated on 1st October 2015 and dismantled on the same day. The analysis period was taken between 24th September and 1st October.

The measurement at this site shows a predominance of 2/3 axle vehicles, typical of local industry delivery and trailer type trucks with an axle pattern of 113 or 123 commonly seen on trunk roads as long haulage vehicles.

As this measurement is on a two-lane highway, both lanes have been analyzed. The majority of the heavier traffic is driving in lane 1, identified by the distributions in the coming diagrams below, where lane 2 is carrying mainly 2/3 axle trucks and busses.

Measurement results are presented in tables 65 and 66 as accumulative statistics for the vehicle groups on different lanes and in figures 74 and 75 as cumulative load distributions on different lanes.

*Table 65. Accumulative statistics for the vehicle groups Eastbound, Lane 1.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 1 966 | 2 157 | 3 832 | 2 603 | 1 180 | 79 | **11 817** |
| Speed (ave.)[1] | 82,72 | 84,45 | 82,46 | 84,01 | 84,00 | 83,20 | **83,37** |
| GVW average | 13,22 | 19,97 | 33,13 | 27,12 | 12,61 | 46,05 | **24,13** |
| Total GVW[2] | 25 990,52 | 43 075,29 | 126 954,16 | 70 593,36 | 14 879,80 | 3 637,95 | **285 144,21** |
| ESAL (Ave.)[3] | 0,57 | 0,53 | 0,83 | 0,70 | 0,40 | 2,22 | **0,67** |

*Table 66. Accumulative statistics for the vehicle groups Eastbound, Lane 2.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 5 | 9 | 71 | 32 | 6 | 1 | **162** |
| Speed (ave.)[1] | 90,32 | 87,97 | 93,79 | 94,34 | 94,56 | 85,28 | **93,34** |
| GVW average | 12,24 | 14,05 | 19,08 | 18,9 | 12,8 | 19,17 | **18,09** |
| Total GVW[2] | 61,20 | 126,45 | 1 354,68 | 604,80 | 76,80 | 19,17 | **2 243,16** |
| ESAL (Ave.)[3] | 0,44 | 0,10 | 0,14 | 0,16 | 0,50 | 0,57 | **0,17** |

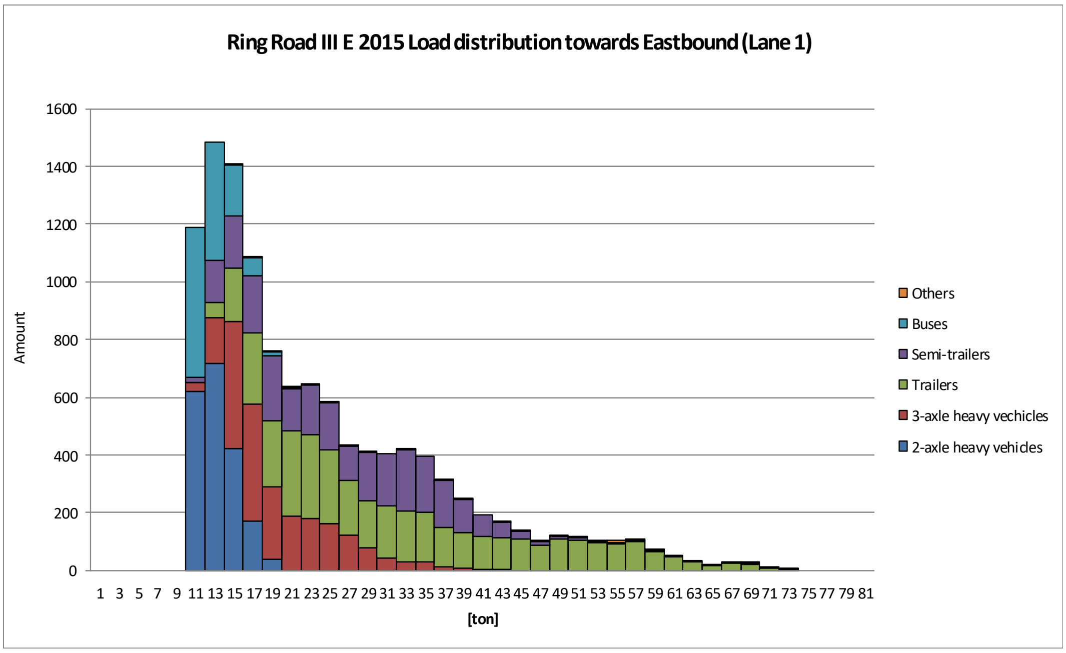



*Figure 74. Load distribution cumulative, Eastbound Lane 1.*

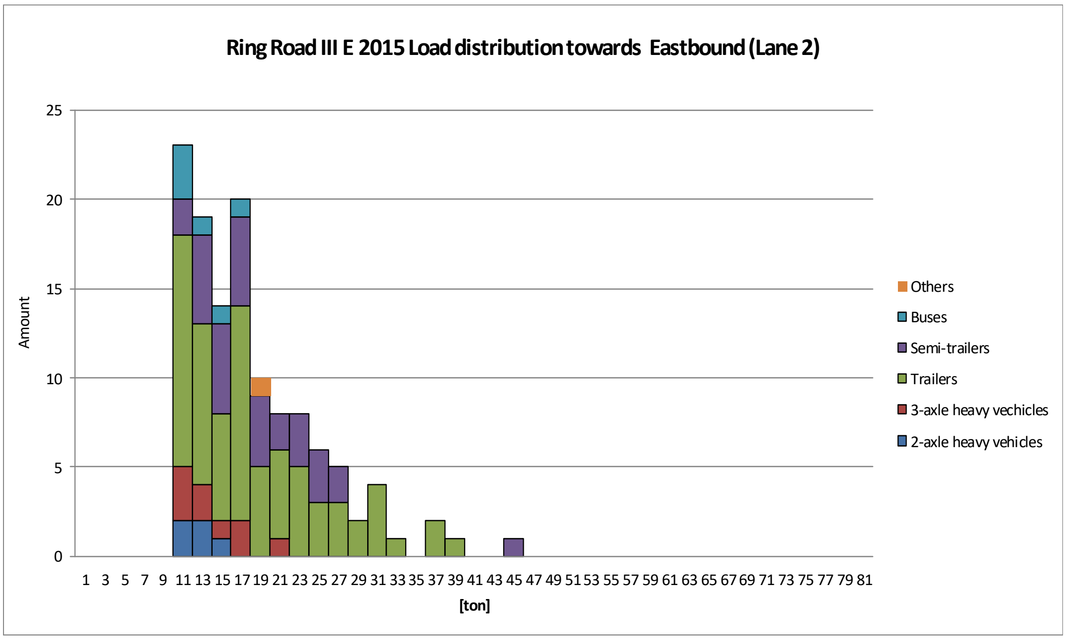



*Figure 75. Load distribution cumulative, Eastbound Lane 2. Note that the Lane 2 (fast lane) has a lot fewer vehicle amount than in Lane 1.*

**Overload results**

Overloads presented in this section are for vehicles in both lanes. From figure 76 and table 67, it can be seen that the percentage of **all** overloaded vehicles is 7,4% in total. That is, with overloads on (all) gross weight, axles or both.

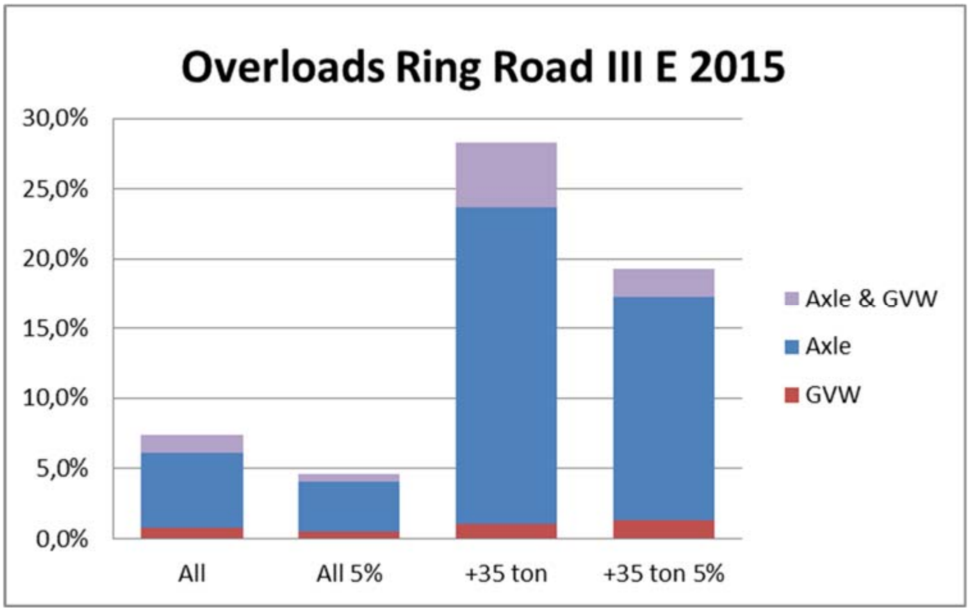



*Figure 76. Overload results from Ring road III bridge (westbound) measurement 2015.*

*Table 67. Overload results from Ring road III bridge (westbound) measurement 2015.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 5,3% | 0,8% | 1,4% | **7,4%** |
| **All 5%** | 3,6% | 0,5% | 0,5% | **4,6%** |
| **+35t** | 22,6% | 1,1% | 4,6% | **28,2%** |
| **+35t +5%** | 15,9% | 1,3% | 2,0% | **19,3%** |

### 3.6.4 Measurement 2017

The weather over the period was mostly overcast with also some rain/clear and sunny. The temperature range was between +7°C to +10°C.

The system was installed on 3rd October and calibrated on 4th October. Calibrations showed a very high accuracy level of A5 across all parameters. The system was re-calibrated on 17th October and dismantled the next day. The analysis period was taken between 11th October and 17th October.

As this measurement is on a two-lane highway, both lanes have been analyzed. The majority of the heavier traffic is driving in lane 1, identified by the distributions in the coming diagrams below.

Measurement results are presented in tables 68 and 69 as accumulative statistics for the vehicle groups on different lanes and in figures 77 and 78 as cumulative load distributions on different lanes.

*Table 68. Accumulative statistics for the vehicle groups Eastbound, Lane 1.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 1 821 | 2 248 | 4 660 | 2 729 | 1 088 | 175 | **12 760** |
| **Speed (ave.)[1]** | 80,67 | 83,22 | 81,22 | 82,45 | 81,77 | 82,75 | **81,83** |
| **GVW average** | 13,67 | 22,25 | 35,48 | 30,45 | 13,57 | 54,72 | **27,25** |
| **Total GVW[2]** | 24 893,07 | 50 018 | 165 336,8 | 83 098,05 | 14 764,16 | 9 576 | **347 710** |
| **ESAL (Ave.)[3]** | 0,64 | 0,77 | 1,13 | 1,07 | 0,47 | 2,81 | **0,94** |

*Table 69. Accumulative statistics for the vehicle groups Eastbound, Lane 2.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 20 | 34 | 106 | 51 | 46 | 5 | **263** |
| **Speed (ave.)[1]** | 89,33 | 92,38 | 94,01 | 101,67 | 96,92 | 112,24 | **95,79** |
| **GVW average** | 13,11 | 17,56 | 24,97 | 23,65 | 12,39 | 43,16 | **20,91** |
| **Total GVW[2]** | 262,2 | 597,04 | 2 646,82 | 1 206,15 | 569,94 | 215,8 | **5 499,33** |
| **ESAL (Ave.)[3]** | 0,52 | 0,4 | 0,56 | 0,61 | 0,4 | 1,95 | **0,54** |

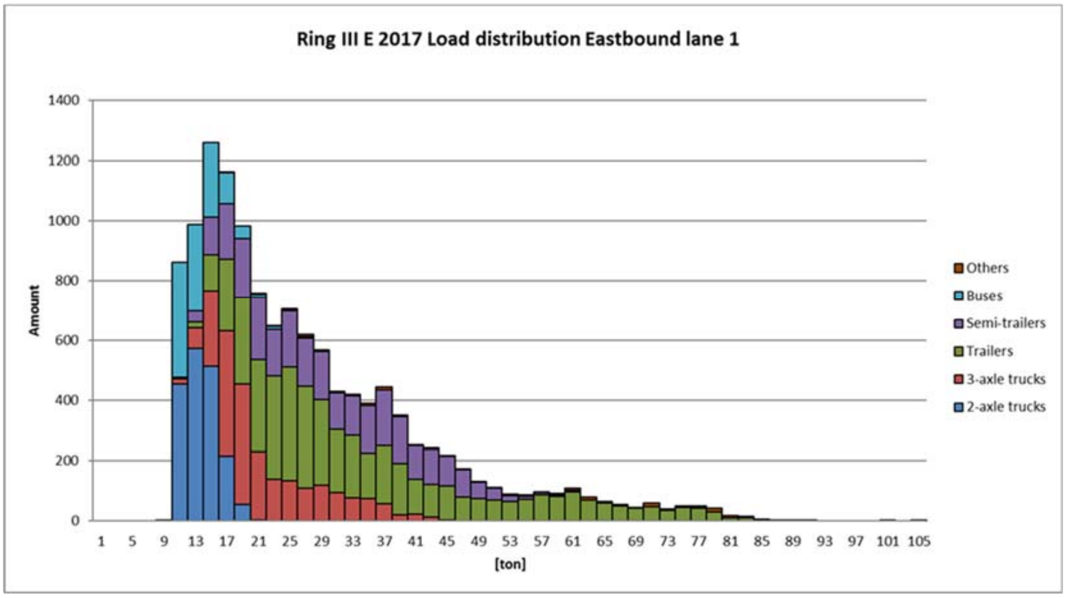



*Figure 77.* *Load distribution cumulative, Eastbound Lane 1.*

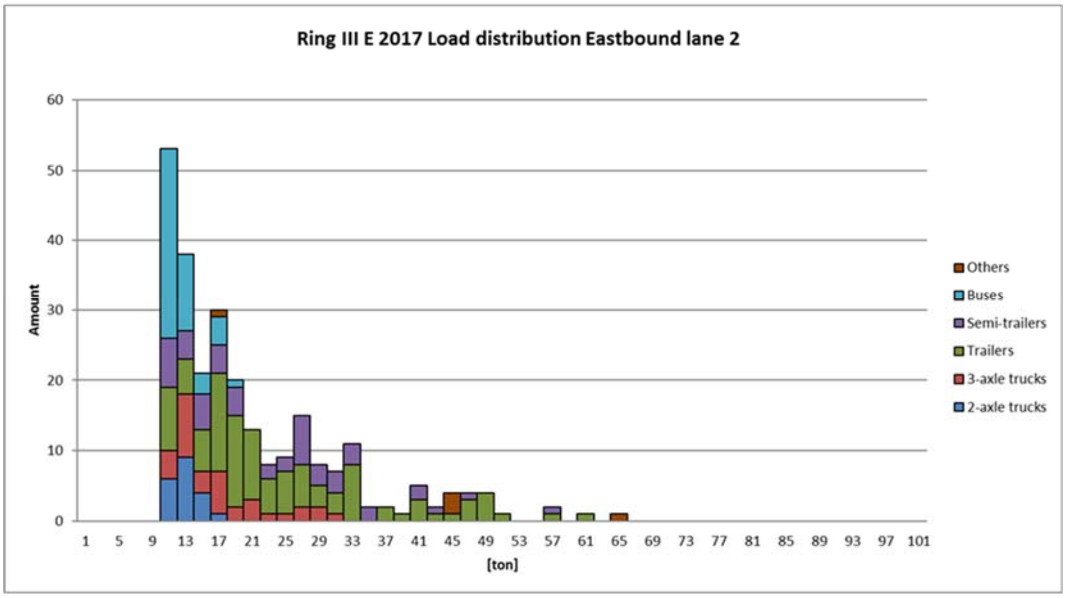



*Figure 78.* *Load distribution cumulative, Eastbound Lane 2. Note that the Lane 2 (fast lane) has a lot fewer vehicle amount than in Lane 1.*

**Overload results**
Overloads presented in this section are for vehicles in both lanes. From figure 79 and table 70, it can be seen that the percentage of **all** overloaded vehicles is 15% in total. That is, with overloads on (all) gross weight, axles or both.

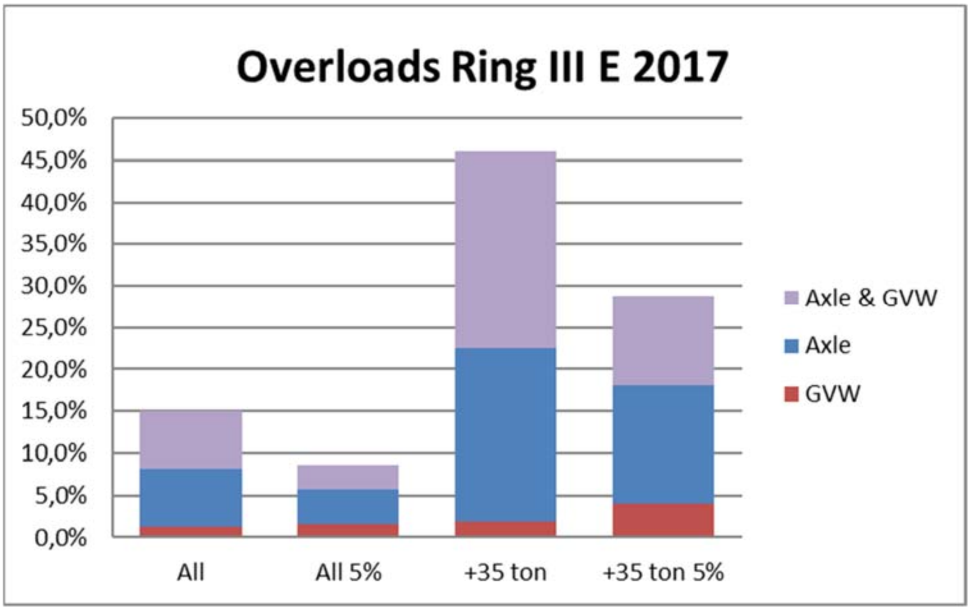



*Figure 79.* *Overload results from Ring road III bridge (westbound) measurement 2015.*

*Table 70.* *Overload results from Ring road III bridge (westbound) measurement 2015.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 6,9% | 1,3% | 6,8% | **15,0%** |
| **All 5%** | 4,0% | 1,7% | 3,0% | **8,6%** |
| **+35t** | 20,6% | 1,9% | 23,6% | **46,1%** |
| **+35t +5%** | 14,1% | 4,0% | 10,6% | **28,7%** |

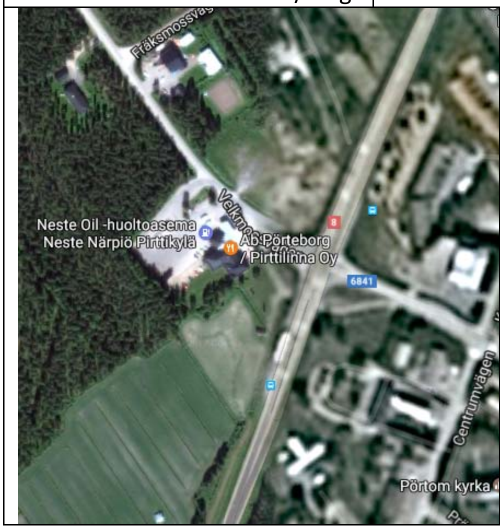
# 3.7 Pirttikylä 2014

### 3.7.1 Overview, E8

The site is situated south of Vaasa on road E8. Traffic was measured in both directions. The northbound driving direction is towards Vaasa and the southbound driving direction is towards Pori.

*Table 71. Bridge data of Pirttikylä bridge.*

| | |
|---|---|
| Bridge name: | Pirttikylä (Esson alikulkukäytävä) |
| Road/Location: | E8 EssoUnderpass Pirttikylä, Närpes (Närpiö) |
| Lanes: | 1+1 |
| Measured direction: | Both Lanes |
| Bridge Id: | V-1760 |
| Bridge type: | Slab/Pre-fabricated construction |
| Coordinate lat/long: | 62.712748, 21.611133 |




Source: Google.com

*Table 72. Measured traffic data from Pirttikylä bridge 2014.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| **Results** | **ESAL** | **# Per day** | **GVW** | **Weight** | **Amount** | **Axle** | **GVW** | **Both** |
| 2014 | 1,31 | 318 | 35,78 t | 79 671 t | 2 227 | 12,0% | 1,5% | 2,2% |


*Figure 80. Special heavy transport vehicle on bridge (left) and bridge from west (right).*

### 3.7.2 Measurement 2014

The weather over the period was reasonable with some light precipitation. The temperature range was between +4°C (night time) to +12°C.

The system was installed on 12th October 2014 and calibrated on 13th October. The system was re-calibrated on 19th October 2014 and dismantled on the same day. The analysis period was taken between 13th October and 19th October.

Of particular interest at this site was the number of special vehicles using this road section. These vehicles were of type 12, 13, 14, 15 and 16 axles and were analyzed separately, as the classification table does not carry configurations for these vehicles.

The calibration was run at two different speeds in an attempt to simulate slow moving vehicles entering the left-hand lane (northerly direction). The turning event for the calibration vehicle was some 8km down the road, and we decided that the driver would attempt a closer turning point, which meant his maximum speed when driving in lane one towards Vaasa was only 40-42 km/h. We did achieve a quite satisfactory calibration with a B10 GVW rating and A5 axles in lane 1, and A5 in lane 2.

Measurement results are presented in tables 73 and 74 as accumulative statistics for the vehicle groups on different lanes and in figures 81 and 82 as cumulative load distributions on different lanes.

*Table 73. Accumulative statistics for the vehicle groups lane 1, towards Vaasa.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 70 | 54 | 751 | 143 | 64 | 35 | **1 117** |
| **Speed (ave.)[1]** | 84,68 | 97,36 | 101,28 | 98,85 | 93,25 | 91 | **98,96** |
| **GVW average** | 12,46 | 20,99 | 42,35 | 38,85 | 15,5 | 38,1 | **37,32** |
| **Total GVW[2]** | 872,2 | 1 133,46 | 31 804,85 | 5 555,55 | 992 | 1 333,5 | **41 686,44** |
| **ESAL (Ave.)[3]** | 0,41 | 0,64 | 1,59 | 1,37 | 0,7 | 2,15 | **1,41** |

Table 74. Accumulative statistics for the vehicle groups lane 2, towards Pori.

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| Total vehicles | 62 | 52 | 693 | 154 | 99 | 50 | **1 110** |
| Speed (ave.)¹ | 82,7 | 86,45 | 93,79 | 89,32 | 67,8 | 85,12 | **89,5** |
| GVW average | 13,47 | 21,91 | 38,03 | 31,65 | 14,68 | 66,44 | **34,22** |
| Total GVW² | 835,14 | 1 139,32 | 26 354,79 | 4 874,1 | 1 453,32 | 3 322 | **37 984,2** |
| ESAL (Ave.)³ | 0,61 | 0,82 | 1,32 | 0,98 | 0,59 | 2,62 | **1,21** |

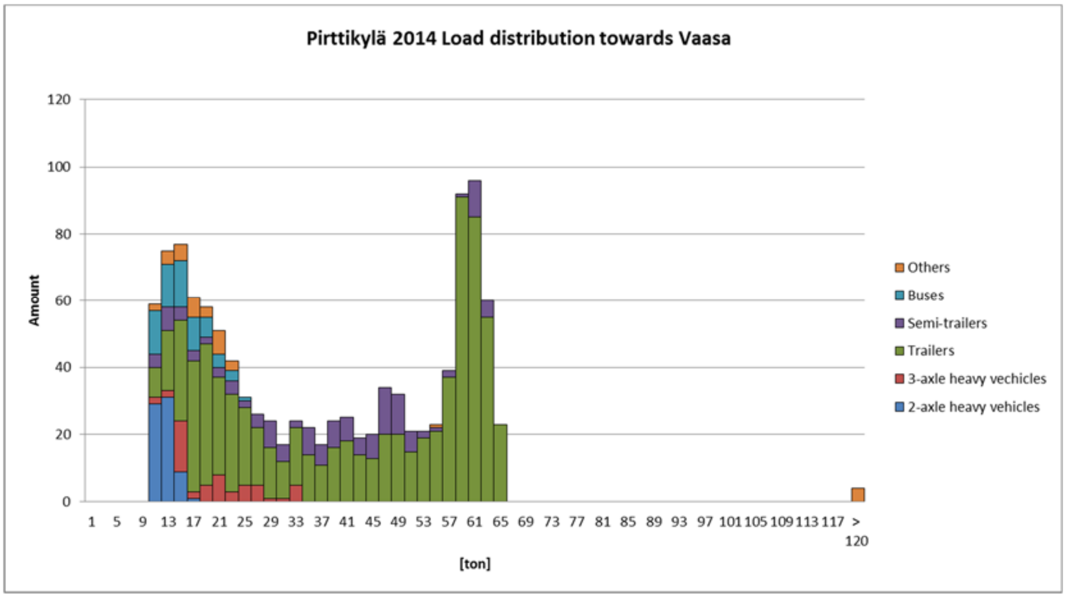



*Figure 81. Load distribution cumulative, towards Vaasa.*

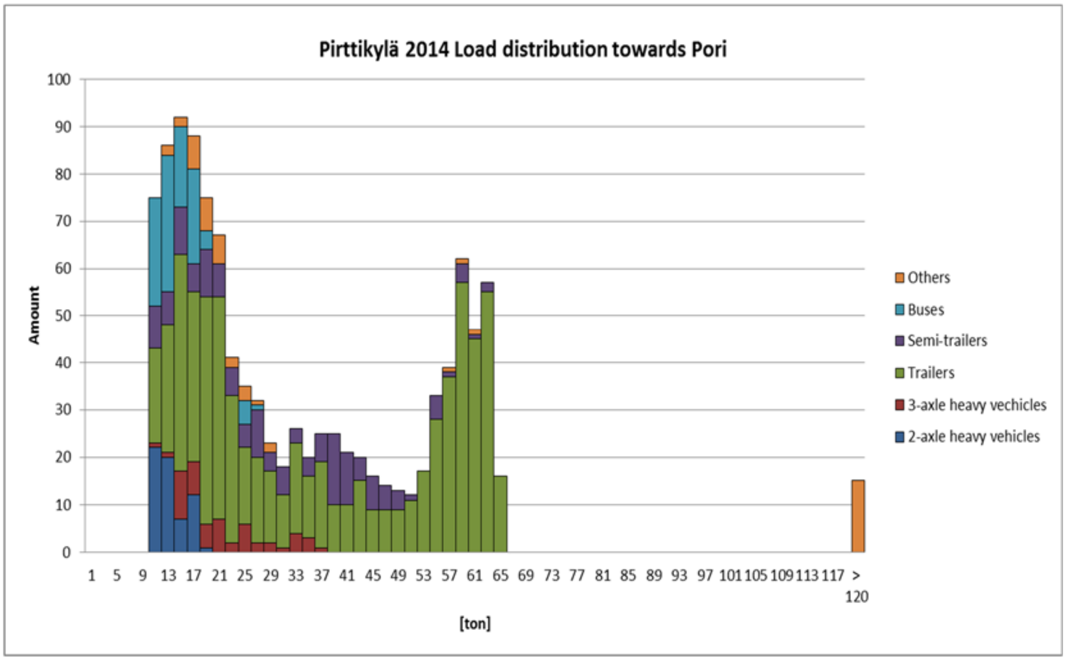



*Figure 82. Load distribution cumulative, towards Pori.*

**Overload results**

Overloads presented in this section are for vehicles in both directions. From figure 83 and table 75, it can be seen that the percentage of all overloaded vehicles is just above 18% in total. That is, with overloads on (all) gross weight, axles or both.

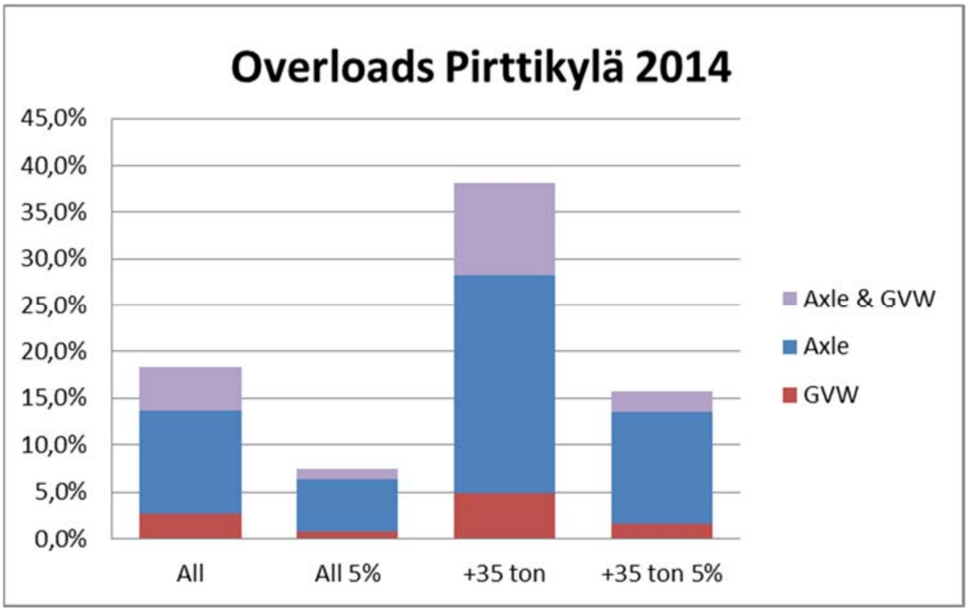



*Figure 83. Overload results from Pirttikylä bridge measurement 2014.*

*Table 75. Overload results from Pirttikylä bridge measurement 2014.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| **All** | 11,0% | 2,6% | 4,7% | **18,3%** |
| **All 5%** | 5,7% | 0,8% | 1,1% | **7,5%** |
| **+35t** | 23,5% | 4,8% | 9,9% | **38,2%** |
| **+35t +5%** | 12,0% | 1,5% | 2,2% | **15,7%** |

**Class 140, Special vehicles extract analyze**
In table 76 are all 23 vehicles (**special transport** vehicles with 14 to 16 axles) in the *unspecified* class 140. This data has been extracted from 'dumped' files, as the SiWIM system does not, at present, recognize any vehicle over 12 axles and would therefore be 'out of classification'.

The accuracies on the vehicle axle distances are very good, producing a very precise upper and lower limit. These upper and lower limits can be expanded to encompass all vehicle types of 14,15 & 16 axles.

*Table 76. All measured 23 special transport vehicles with 14 to 16 axles in the unspecified class 140.*

| Timestamp | Axles | Class | Axle conf | Gvw (kN) | Gvw (tons) |
|---|---|---|---|---|---|
| 2014-10-13-07-49-16-018 | 7 | 140 | 2212 | 562,8 | 57,4 |
| 2014-10-14-06-10-32-371 | 9 | 140 | 2322 | 543,7 | 55,4 |
| 2014-10-14-13-34-14-514 | 8 | 140 | 134 | 586,3 | 59,8 |
| 2014-10-16-21-43-26-568 | 8 | 140 | 12311 | 594,6 | 60,6 |
| 2014-10-22-06-00-18-700 | 14 | 140 | 11210 | 1398,66 | 142,6 |
| 2014-10-22-19-32-55-048 | 14 | 140 | 11210 | 1409,71 | 143,7 |
| 2014-10-15-13-31-04-842 | 14 | 140 | 1310 | 1308,25 | 133,4 |
| 2014-10-16-14-38-21-364 | 14 | 140 | 1310 | 1443,65 | 147,2 |
| 2014-10-17-17-34-00-590 | 14 | 140 | 1310 | 1434,07 | 146,2 |
| 2014-10-17-21-11-26-173 | 15 | 140 | 11238 | 1851,26 | 188,8 |
| 2014-10-20-15-20-01-828 | 15 | 140 | 1338 | 1978,55 | 201,8 |
| 2014-10-20-15-37-57-237 | 15 | 140 | 11238 | 1885,73 | 192,3 |
| 2014-10-17-17-34-05-756 | 16 | 140 | 1312 | 1423,94 | 145,2 |
| 2014-10-20-06-23-18-991 | 16 | 140 | 1312 | 1903,7 | 194,1 |
| 2014-10-21-18-00-35-064 | 16 | 140 | 1312 | 1925,73 | 196,4 |
| 2014-10-22-19-33-02-924 | 16 | 140 | 1312 | 1419,54 | 144,8 |
| 2014-10-13-06-41-04-864 | 16 | 140 | 11212 | 1882,92 | 192,0 |
| 2014-10-13-06-41-12-158 | 16 | 140 | 1312 | 1819,24 | 185,5 |
| 2014-10-13-15-33-10-333 | 16 | 140 | 1312 | 2100,98 | 214,2 |
| 2014-10-14-06-04-54-461 | 16 | 140 | 11212 | 1917,42 | 195,5 |
| 2014-10-15-13-31-10-912 | 16 | 140 | 11212 | 1206,89 | 123,1 |
| 2014-10-16-06-20-03-768 | 16 | 140 | 1312 | 1659 | 169,2 |
| 2014-10-17-13-21-52-825 | 16 | 140 | 11212 | 1984,85 | 202,4 |

Increasing the upper and lower parameters on the axle distances would mean that some configurations would be changed. For example, a 112 (12) would become a 13 (12), as the difference between these axles is marginal (1,31-2,02 = 0,7m). This would have no effect on the overall result and all vehicles in this class would be configured as 13 (12).

From the data and tables above, it is possible to create 3 new vehicle classes to satisfy all the parameters. These new vehicle classes are shown in table 68 below.

From the data above the maximum gross weight is 2100Kn = 214,24 tons and the highest individual axle is 150,528Kn = 15,349 tons, and these vehicles were at a speed of 17,75m/s (63,91kph) and 22,016m/s (79,26kph) respectively. As the time stamps for the passage of vehicles are given, it may be possible to trace the documentation for these vehicles.

*Table 77. 3 new classes for special transport vehicles created in the study of Pirttikylä bridge.*

| Classification | Axles | Parameters | Axle 1-2 | Axle 2-3 | Axle 3-4 | Axle 4-5 | Axle 5-6 | Axle 6-7 | Axle 7-8 | Axle 8-9 | Axle 9-10 | Axle 10-11 | Axle 11-12 | Axle 12-13 | Axle 13-14 | Axle 14-15 | Axle 15-16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 141 | 14 | Original Range | 1,83-3,31 | 1,37-1,99 | 1,44-1,51 | 2,23-2,70 | 1,50-1,67 | 1,44-1,54 | 1,46-1,55 | 1,41-1,52 | 1,41-1,51 | 1,37-1,46 | 1,41-1,51 | 1,44-1,55 | 1,46-1,63 | | |
| | | New Class Range | 1,6-3,5 | 1,3-2,2 | 1,3-1,8 | 2,0-3,0 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | | |
| 142 | 15 | Original Range | 1,76-2,42 | 1,45-1,95 | 1,42-1,55 | 2,57-2,94 | 1,56-1,67 | 1,45-1,53 | 2,77-2,90 | 1,56-1,61 | 1,38-1,51 | 1,45-1,51 | 1,42-1,53 | 1,45-1,51 | 1,42-1,47 | 1,52-1,59 | |
| | | New Class Range | 1,6-3,0 | 1,32-2,2 | 1,3-1,8 | 2,0-3,3 | 1,32-1,8 | 1,32-1,8 | 2,2-3,3 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | |
| 143 | 16 | Original Range | 1,80-2,60 | 1,31-2,02 | 1,36-1,54 | 2,22-3,09 | 1,43-1,72 | 1,36-1,54 | 1,37-1,52 | 1,39-1,54 | 1,36-1,54 | 1,31-1,59 | 1,32-1,54 | 1,35-1,59 | 1,39-1,54 | 1,36-1,59 | 1,43-1,63 |
| | | New Class Range | 1,6-3,0 | 1,25-2,2 | 1,25-1,8 | 2,0-3,3 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 | 1,32-1,8 |

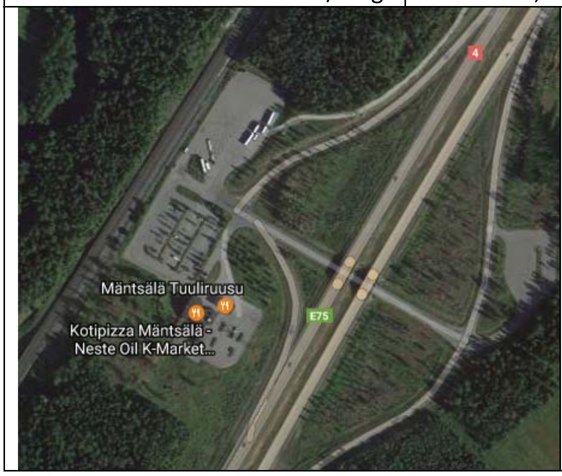
# 3.8 Mäntsälä 2016

### 3.8.1 Overview, E75

The site is situated south Mäntsälä on highway 4, Hirvihaara underpass. Traffic was measured in northbound direction on 2 lanes, towards Lahti.

*Table 78. Bridge data of Mäntsälä bridge.*

| | |
|---|---|
| Bridge name: | Hirvihaara Underpass Mäntsälä (Hirvihaaran alikulkusilta) |
| Road/Location: | E75 |
| Lanes: | 2 lanes |
| Measured direction: | Northerly direction only |
| Bridge Id: | |
| Bridge type: | Slab form concrete construction |
| Coordinate lat/long: | 60.604808, 25.256621 |




Source: Google.com

*Table 79. Measured traffic data from Mäntsälä bridge 2016.*

| | Average per heavy vehicle | | | Heavy vehicles, Total | | Overloads +35 t +5% filter | | |
|---|---|---|---|---|---|---|---|---|
| **Results** | **ESAL** | **# Per day** | **GVW** | **Weight** | **Amount** | **Axle** | **GVW** | **Both** |
| 2016 | 1,16 | 931 | 31,42 t | 204 704 t | 6 516 | 19,6% | 1,2% | 7,4% |

### 3.8.2 Measurement 2016

Despite 'on site' investigation of bridge before measurements and during process of measured data, extremely high dynamic and low axle definition has been seen by Cestel. There are also problems with lifting axles, a lot of them are hardly touching the surface of the road. Despite this Trafikia was quite confident with the results but it is proposed there should be no further measurements on this bridge location.

As this measurement is on a two-lane highway, both lanes have been analyzed. The majority of the heavier traffic is driving in lane 1, identified by the distributions in the diagrams below, where lane 2 is carrying mainly 2 / 3 axle trucks and busses.

Measurement results are presented in tables 80 and 81 as accumulative statistics for the vehicle groups on different lanes and in figures 84 and 85 as cumulative load distributions on different lanes.

*Table 80. Accumulative statistics for the vehicle groups, northbound lane 1.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 342 | 415 | 3 614 | 1 207 | 722 | 165 | **6 480** |
| **Speed (ave.)[1]** | 87,21 | 88,61 | 85,65 | 89,39 | 95,88 | 89,11 | **87,85** |
| **GVW average** | 14,08 | 23,65 | 36,2 | 32,03 | 17,47 | 41,11 | **31,4** |
| **Total GVW[2]** | 4 815,36 | 9 814,75 | 130 826,8 | 38 660,21 | 12 613,34 | 6 783,15 | **203 472** |
| **ESAL (Ave.)[3]** | 0,86 | 1,03 | 1,23 | 1,15 | 0,98 | 1,5 | **1,16** |

*Table 81. Accumulative statistics for the vehicle groups, northbound lane 2.*

| Vehicle group | 2-ax. laden trucks | 3-ax. laden trucks | Trailers | Semi-Trailers | Buses | Others | All vehicles |
|---|---|---|---|---|---|---|---|
| **Total vehicles** | 2 | 1 | 20 | 2 | 23 | 3 | **51** |
| **Speed (ave.)[1]** | 83,48 | 92,66 | 84,85 | 86,19 | 94,11 | 99,94 | **90,07** |
| **GVW average** | 16,8 | 17,54 | 33,4 | 32,74 | 15,02 | 23,62 | **23,55** |
| **Total GVW[2]** | 33,6 | 17,54 | 668 | 65,48 | 345,46 | 70,86 | **1 201,05** |
| **ESAL (Ave.)[3]** | 1,63 | 0,38 | 1,56 | 1,43 | 0,9 | 1,16 | **1,21** |

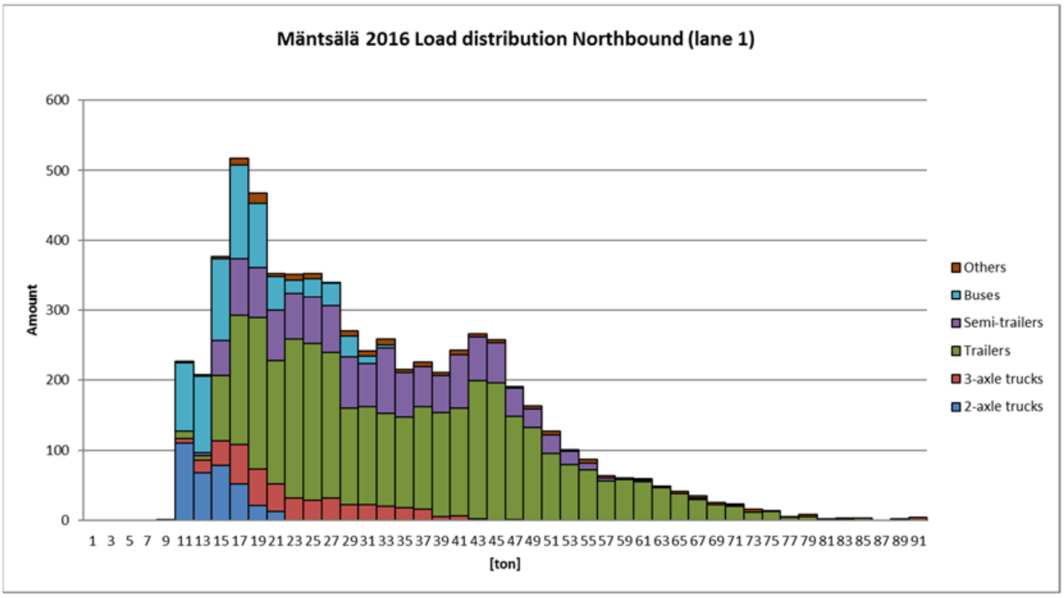



*Figure 84. Load distribution cumulative, northbound lane 1.*

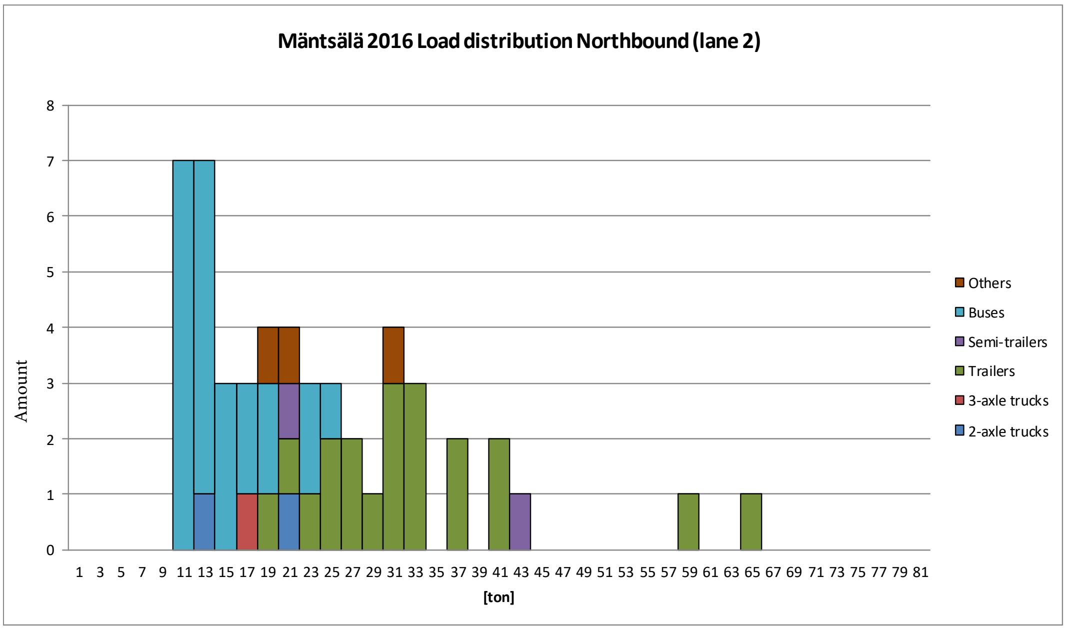



*Figure 85. Load distribution cumulative, northbound lane 2.*

**Overload results**

Overloads presented in this section are for vehicles in both northbound lanes. From figure 86 and table 82, it can be seen that the percentage of all overloaded vehicles is around 21% in total. That is, with overloads on (all) gross weight, axles or both.

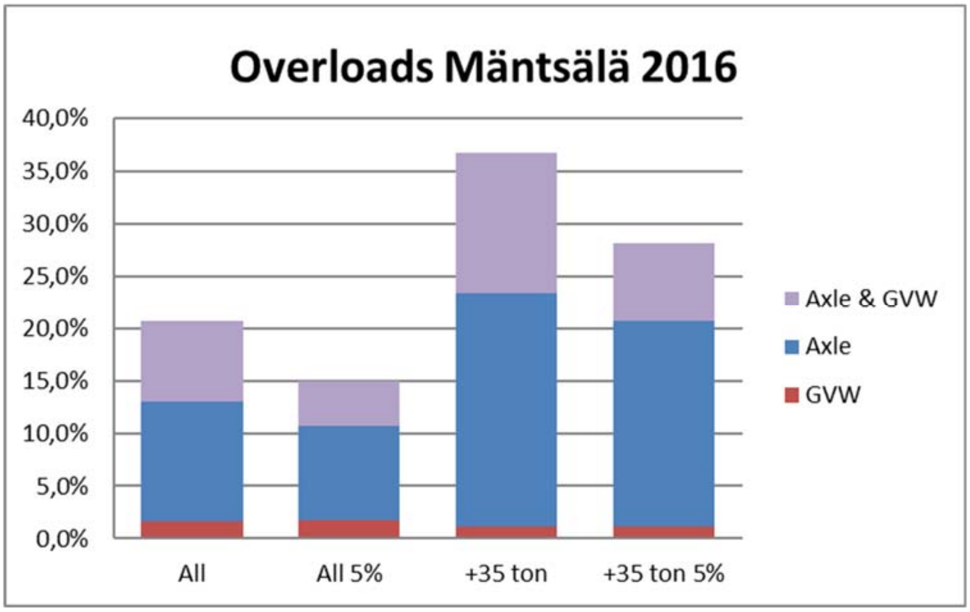



*Figure 86. Overload results from Mäntsälä bridge measurement 2016.*

*Table 82. Overload results from Mäntsälä bridge measurement 2016.*

| Overloads | Axle | GVW | Axle & GVW | Total |
|---|---|---|---|---|
| All | 11,4% | 1,7% | 7,7% | 20,7% |
| All 5% | 9,0% | 1,7% | 4,3% | 15,0% |
| +35t | 22,2% | 1,1% | 13,4% | 36,7% |
| +35t +5% | 19,6% | 1,2% | 7,4% | 28,1% |

# 4 Analysis results from measurements

## 4.1 ESAL, NAL and vehicle types

**Introduction**
Data on traffic loads are an essential element of the design, construction and maintenance of road structures, pavements and bridges. Traffic load is the sum of the loads of all individual vehicles and cause fatigue of the carriageway structure of the materials, thus the onset and progression of damage to the road surfaces.

The impact of the vehicle on the fatigue of carriageway construction materials built can be evaluated with its equivalency factor ESAL. Traffic load is the sum of ESALs of all trucks, which in a certain period of time (day, year of the project period) traversing the cross-section of the carriageway.

Road pavements are structures with finite lives. They are designed to withstand a specific number of equivalent single axle loads (ESALs). Consequently, the truck traffic consumption of ESAL design life, and increased road infrastructure costs associated with it, can increase rapidly where significant volumes of truck traffic is involved. If a road section was not designed for heavy axle loads, it could be rendered inadequate in a matter of months or even weeks. When repairs, reinforcements or new constructions are planned, they involve analyzing available traffic data, where usually only traffic counters data is available. Since investments are high, any additional input, to help with decision, is highly anticipated and desired.

ESAL of the vehicle can only be determined by weighing each of its axles. It would be ideal, to statically weigh each axle of each truck, which is not possible in practice, since it is not possible to stop every truck. Therefore, systems have been developed for weighing commercial vehicles in motion (WIM - Weigh-In-Motion), first in slow motion (SS WIM - Slow Speed WIM), and later in a free-flow (HS WIM - High Speed WIM). WIM measurements in free-flow can be further divided according to the mode of installation on the road (Pavement WIM) and bridge (Bridge WIM).

**Equivalency factors of commercial vehicles and traffic loads**

The impact of the vehicle on the pavement fatigue evaluate its equivalency factor ESAL, which can only be determined by weighing the individual axles.

When we have weighed all the axles of the vehicle, we are able to calculate its equivalency factor ESAL expressed by the number of passages of nominal axle which has two dual tires and axle load of 100 kN ($ESAL_{100kN}$). Truck ESAL is calculated from the sum of the individual contributions of the axle loads of the vehicle to the actual arrangement of the axles and wheels $ESAL_{a,w}$, according to the equation:

$$ESAL = \sum ESAL_{a,w} = 10^{-4} \cdot \sum_{i=1}^{N} f_{a,i} \cdot \left(f_{w,i} \cdot A_i\right)^4$$

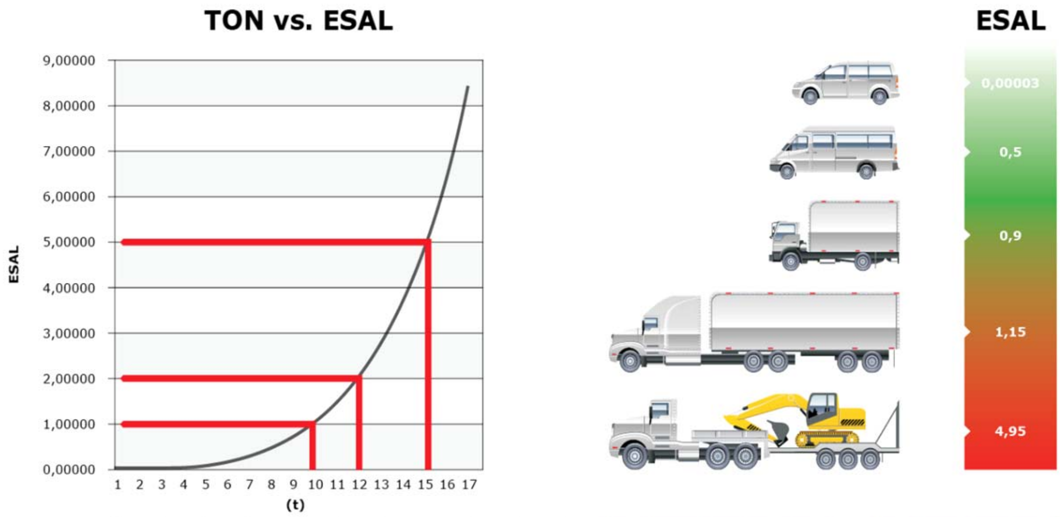
where

$f_{a,i}$ - axle type factor (1,0 for single, 0,0953 for double and 0,0301 for triple)
$f_{w,i}$ - wheel type factor (1,0 for double, 1,2 for super single, 1,3 for single)
$A_i$ - load in tons
$N$ - number of axles

ESAL increases with the fourth power compared to the load on the axle, so for example, 20% exceeded axle load (12 tons instead of 10 tons) more than doubled its equivalency factor and thus traffic load (Figure 87).

Traffic load is calculated based on available traffic data:

- theoretical traffic load is calculated from the number of vehicles by category, and their average ESAL factor,
- actual traffic load is determined by weighing commercial vehicles in free-flow, which weigh each axle and determine the actual ESAL for individual vehicles.




| TON | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESAL | 0,0001 | 0,0016 | 0,0081 | 0,0256 | 0,0625 | 0,1296 | 0,2401 | 0,4096 | 0,6561 | **1,0000** | 1,4641 | 2,0736 | 2,8561 | 3,8416 | 5,0625 | 6,5536 | 8,3521 | 10,4976 | 13,0321 | 16,0000 |

*Figure 87. Relation between ESAL and axle load.*

**Setting average theoretical traffic load factors**

For the determination of traffic volumes every vehicle should be weighed calculated its ESAL, then sum all the individual ESAL values. But in the real world this cannot be done, therefore, according to the hundred thousand of ESAL calculations and years of measurements average $ESAL_v$ for different representative vehicle was calculated mostly from the traffic counters data. The results are related to the types of vehicles. Mean $ESAL_v$ values for representative vehicles have been defined on the basis of real traffic, which means that some vehicles were empty and some partially full, some full, some also overloaded.

All these calculations with the average traffic load fit in the normal flow of traffic when traffic in both directions is alike. Problem and a big error in the calculations of traffic loads can occur in cases where the traffic in one direction runs mostly with fully loaded (and even overloaded) commercial vehicles, but in the other direction most of the vehicles are empty, like construction of major infrastructure or other objects or traffic to the quarries.

**Actual traffic load – WIM system**

In comparison to the theoretical ESAL values, determined for different vehicle types, actual weighing with WIM system provides actual traffic load and realistic ESAL values. Weigh in motion is also only solution for actual information about the empty, loaded and overloaded vehicles. Discrepancy between theoretical ESAL value and actual, measured one, can be as high as 500%.

**"Asymmetrical" heavy vehicles traffic**

So called "asymmetrical" freight traffic is related to very uneven traffic load per lane/direction. This is happening in the construction of infrastructure facilities in the surrounding quarries, gravel pits and mines, as well as in wood harvesting. In this case, the calculation of traffic load equivalency factors with average theoretical $ESAL_v$ fails completely as traffic counters only record the number of vehicles by vehicle category and do not distinguish between empty and full, or even overloaded vehicles. Usage of the WIM system is a must in such cases. If we assume that on a certain stretch of the road to the quarry daily leads *X* empty commercial vehicles and full from the quarry, their theoretical and actual traffic loads will differ for up to 5 times, compared to theoretical values and even more if actual values for most overloaded vehicle compared to empty one is calculated.

**Nominal axle load**

Traffic loads therefore have values ranging from very mild to severe. For the dimensioning of pavement structures and renovations, the traffic load is essential information, because a direct influence on the choice of materials and thicknesses of the layers in the carriageway structure of the materials, thereby naturally also on the cost of the construction, maintenance and renewal, but also on the life of the pavement.

In dimensioning stage of road design, accurate ESAL value is a must. Traffic loads from only one (more heavily loaded, if available) direction is used for design and/or reconstruction calculations and 10 (20) year average is calculated. The result is called 10(20)-year nominal axle loading (NAL). So, basic difference between average daily ESAL and daily NAL is, that average daily ESAL sums all ESAL values from all vehicles in a day, where NAL uses more heavily loaded lane, if available, or half the ESAL value per day if data per lane is not available.

**Vehicle types and traffic loads**

Different types of vehicles use different axle configurations and different tyre configurations. To accurately evaluate traffic load on a road section, these configurations should be well known in advance or just an estimation on the actual traffic load can be done.

If we take for an example a typical 1R2S3 semitrailer, we do have several different tyre/axle configurations. As an axle configuration, it is important to know exact distance between the axles within a group, as tridem can easily become three single axles, where impact to the road surface is different. Tyre configuration is also important. One can expect double tyre on a driving axles and singles on the others, but this can also be true for super single on driving axles and also super singles on the trailer or even double tyres on the trailer. Study is a must to determine actual configurations that is predominant for each vehicle type. At least several thousands of vehicles should be observed to reach any reliable conclusion, where at least a hundred vehicles of a same type should be analyzed.

**Practical examples on ESAL calculation**

Finnish Transport Agency uses in their Final report on Axle Load Study 2013-2014 (67eng 2015) equation in figure 88 for calculation of load equivalence for axles, which is also fourth power equation with some specifics.

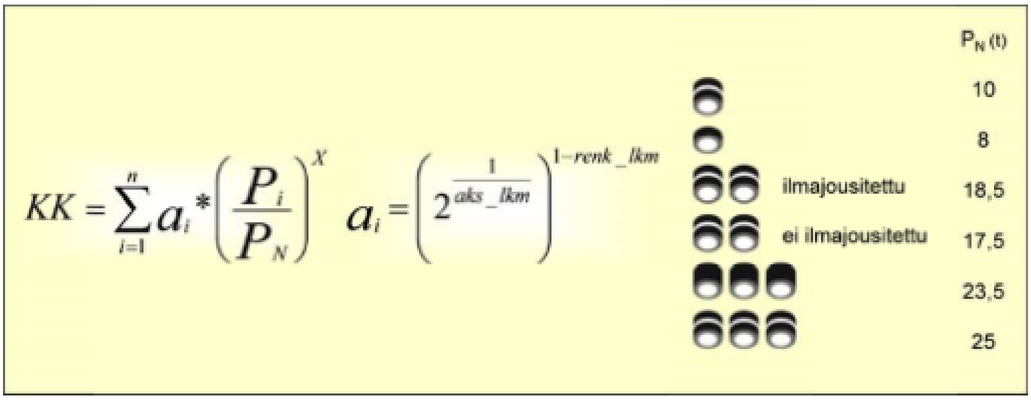



*Figure 88.* *Equation for equivalence factor KK.*

In the figure 88 the terms are:

| | | |
|---|---|---|
| *KK* | = | equivalence factor |
| *aks_lkm* | = | amount of axles |
| *renk_lkm* | = | amount of tyres |
| $P_n$ | = | reference load in [t] |

It is also mentioned in the document, that variable factor $a_i$ is not used in the study. Reference load is defined for each axle configuration, as described in table 83 below. Values in italic were interpolated or deducted from values in bold.

*Table 83.* *Reference load $P_n$ for different tyre/axle combinations.*

| Axles \ Tyre | Double | | Supersingle | | Single | |
|---|---|---|---|---|---|---|
| | air | spring | air | spring | air | spring |
| 1 | **10** | *9,7* | *9* | *8,7* | **8** | *7,7* |
| 2 | **18,5** | **17,5** | *17,39* | *16,406* | *14,8* | *13,892* |
| 3 | **25** | **24** | **23,5** | **22,5** | *20* | *19,052* |

Using some reference values, both equations for calculation of equivalency factors are compared here. It should be noted, that equation in figure 78 above differs significantly from most of other equations for ESAL calculation, especially when using variable factor $a_i$ since it uses 10 t single axle with single tyres as a reference axle, where all other equations use 10 t single axle with double tyres. Comparison of some reference axles with equivalency factors from two different calculations were made in table 2. For the ease of calculation, air suspension was presumed with all calculations.

*Table 84. Different tyre/axle combinations and KK / ESAL values.*

| # of Axles | Tyres | [t] | KK without ai | KK | ESAL |
|---|---|---|---|---|---|
| 1 | Double | 8 | **0,41** | **0,2** | **0,41** |
| 1 | Double | 10 | **1** | **0,5** | **1** |
| 1 | Double | 12 | **2,07** | **1,04** | **2,07** |
| 1 | Double | 15 | **5,06** | **2,53** | **5,06** |
| 1 | Single | 8 | **1** | **1** | **1,17** |
| 1 | Single | 10 | **2,44** | **2,44** | **2,85** |
| 1 | Single | 12 | **5,06** | **5,06** | **5,92** |
| 1 | Single | 15 | **12,36** | **12,36** | **14,46** |
| 2 | Double | 16 | **0,56** | **0,4** | **0,62** |
| 2 | Double | 18 | **0,9** | **0,63** | **1** |
| 2 | Double | 20 | **1,37** | **0,97** | **1,52** |
| 2 | Single | 16 | **1,37** | **1,37** | **1,78** |
| 2 | Single | 18 | **2,19** | **2,19** | **2,86** |
| 2 | Single | 20 | **3,33** | **3,33** | **4,35** |
| 3 | Double | 20 | **0,41** | **0,33** | **0,48** |
| 3 | Double | 25 | **1** | **0,79** | **1,18** |
| 3 | Double | 30 | **2,07** | **1,65** | **2,44** |
| 3 | Single | 20 | **0,41** | **0,41** | **1,38** |
| 3 | Single | 25 | **1** | **1** | **3,36** |
| 3 | Single | 30 | **2,07** | **2,07** | **6,96** |

KK calculation without $a_i$, as used in Final report, shows same results as standard ESAL calculation with single axle and double tyre, but all other values are lower, especially with tridem and single tyres, as used in semitrailers. By using KK with $a_i$, all values are significantly lower than those from ESAL calculation.

As a more practical representation of different calculations, several vehicle types with typical axle loads below are prepared here. Again, with all presented cases, air suspension will be used in calculations. In table 85 below (also table 21 in Final report), a typical vehicle, representing each vehicle type is shown. In addition to that, another vehicle, which was detected on Finnish roads, type KAVP2 (MODULE) was also used as a last example. Calculations are presented in tables 86 – 90. All vehicles were presented as fully loaded.

*Table 85. Vehicle types, used in example calculation.*

| Type | Picture | ESAL | |
|---|---|---|---|
| | | 2014 | 1999 |
| KAIP |  | 0.88 | 0.58 |
| KAPP |  | 1.29 | 1.48 |
| KAVP |  | 2.46 | 2.63 |
| MODULE |  | 1.83 | - |

*Table 86. KAIP – 3 axle rigid truck.*

| Axle group | 1 | 2 | SUM |
|---|---|---|---|
| Weight [t] | 6 | 18 | 24 |
| Tyres | 1 | 2 | |
| KK without $a_i$ | 0,32 | 0,9 | 1,22 |
| KK | 0,32 | 0,63 | 0,95 |
| ESAL | 0,37 | 1 | 1,37 |

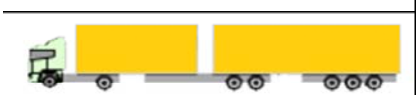
*Table 87. KAPP – 6 axle semitrailer.*

| Axle group | 1 | 2 | 3 | SUM |
|---|---|---|---|---|
| Weight [t] | 6 | 18 | 24 | 48 |
| Tyres | 1 | 2 | 1 | |
| KK without $a_i$ | 0,32 | 0,9 | 2,07 | 3,29 |
| KK | 0,32 | 0,63 | 2,07 | 3,02 |
| ESAL | 0,37 | 1 | 2,85 | 4,22 |

*Table 88. KAVP1 – 8 axle truck with trailer.*

| Axle group | 1 | 2 | 3 | 4 | SU |
|---|---|---|---|---|---|
| Weight [t] | 6 | 18 | 16 | 24 | |
| Tyres | 1 | 2 | 1 | 1 | |
| KK without $a_i$ | 0,32 | 0,9 | 1,37 | 2,07 | 4, |
| KK | 0,32 | 0,63 | 1,37 | 2,07 | 4, |
| ESAL | 0,37 | 1 | 1,78 | 2,85 | |

*Table 89. MODULE – 7 axle semitrailer with semitrailer.*



| Axle group | 1 | 2 | 3 | 4 | SU |
|---|---|---|---|---|---|
| Weight [t] | 6 | 10 | 16 | 24 | |
| Tyres | 1 | 2 | 1 | 1 | |
| KK without $a_i$ | 0,32 | 1 | 1,37 | 2,07 | 4, |
| KK | 0,32 | 0,5 | 1,37 | 2,07 | 4, |
| ESAL | 0,37 | 1 | 1,78 | 2,85 | |

*Table 90. MODULE – 11 axle truck with trailer with semitrailer.*

| Axle group | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| Weight [t] | 6 | 18 | 16 | 24 | 2 |
| Tyres | 1 | 2 | 1 | 1 | |
| KK without $a_i$ | 0,32 | 0,9 | 1,37 | 2,07 | 2,0 |
| KK | 0,32 | 0,63 | 1,37 | 2,07 | 2,0 |
| ESAL | 0,37 | 1 | 1,78 | 2,85 | 2,8 |

The same pattern is visible in all examples; ESAL calculation shows higher values than any version of KK calculation, either with or without $a_i$. The biggest difference between KK with $a_i$ or KK without $a_i$ is within single driving axle with double tyres, where 100% difference is detected. Comparing KK and ESAL, lower difference is detected, but highest is within tridem on single tyres.

## 4.2 Accuracy classes

The following information on next two pages is an ***extract*** from the original COST323 document:

ASSESSMENT OF THE ACCURACY AND CLASSIFICATION OF WEIGH-IN-MOTION SYSTEMS Part II - EUROPEAN SPECIFICATION (B. Jacob, E.J. O'Brien, and W. Newton)

At the time of writing (2000), there was no official European standard for WIM and few recent national specifications (METT-LCPC 1993, VIEA 1994, NWML 1995). Consequently, there was a strong demand for such a document in the WIM industry and this task was one of the highest priorities of the COST 323 action on WIM of road vehicles, COST 323 (1993). Two years were spent initially analyzing existing and emerging specifications (ASTM 1994, OIML 1996) and other technical documents (Gillmann, 1992), and preparing the table of contents. The European Specification was subsequently drafted between May 1996 and January 1997. It was then discussed with the European manufacturers and users' representatives. Comments were received and addressed in a revised draft published in June 1997 (COST 323 (1997a)). The main improvement for users was the addition of an appendix giving simplified requirements, not presented in detail in this paper, which contain only the most important clauses and some simplified rules.

Central to the specification is the definition of seven accuracy classes, A(5), B+(7), B(10), C(15), D+(20), D(25) and E. The latter is divided into further classes: E(35), E(40), etc.. The highest accuracy levels (A(5) and B+(7)) are recommended for legal purposes, such as overload enforcement, if current legislation applicable at the site allows the use of WIM for that purpose. The intermediate levels (B(10) and C(15)) are recommended for overload pre-selection, and for detailed traffic analysis involving the use of axle loads and gross weights. Such data might be used for applications in bridge and pavement engineering, design and maintenance. The lowest levels (D+(20) and D(25)) are mainly required for economical and technical studies and general traffic evaluation and management. Obviously, the rougher the pavement, the lower will be the accuracy of a WIM system. Therefore in some circumstances, users may accept a system in a lower class than desired in order to obtain measurements on a medium quality road. Classes E are applicable some low cost or portable WIM systems, or are encountered for common WIM systems installed on rough roads or with pavements in poor condition.

To be in a given class, there must be an acceptable level of confidence that WIM weights will be within a specified percentage of the reference (usually static) values. The numbers in brackets indicate the allowable relative error (in %) in gross vehicle weight but there are also specified error limits for the weights of groups of axles (i.e., successive axles with spacing less than 2 m), individual single axles and axles of a group taken individually.

### Calibration

Pre-weighed calibration trucks are favored above all other methods because they are simple, direct and applicable to all forms of WIM. Such methods can partially remove the effects of spatial repeatability if the calibration truck or trucks are subject to the same repeatability effect as vehicles in the normal traffic flow.

The specification defines four levels of repeatability/reproducibility test conditions as follows:

- Full Repeatability Conditions (r1): One vehicle passes several times at the same speed, load and lateral position.
- Extended Repeatability Conditions (r2): One vehicle passes several times at different speeds, different loads and with small variations in lateral position (in accordance with typical traffic).
- Limited Reproducibility Conditions (R1): A small set of vehicles (typically 2 to 10), representative in weight and silhouette of typical traffic, is used. Each vehicle passes several times, at different combinations of speed and load and with small variations in lateral position.
- Full Reproducibility Conditions (R2): A large sample of vehicles (some tens to a few hundred), taken from the traffic flow and representative of it, is used for the calibration.

### Accuracy classification

The WIM system accuracy classification is based on comparisons of measured results against reference values which, it is anticipated, would generally be determined by statically weighing trucks. To comply with a given accuracy class, the calculated probability that individual results are within the confidence interval [$W_s(1-\delta)$, $W_s(1+\delta)$] or that individual relative errors are within the confidence interval [$-\delta$,$+\delta$] must exceed a specified minimum, $\pi_0$. The confidence interval width, $\delta$, is a function of the accuracy class and the specified values are given (in the table 85 below) for each entity (gross weight, single axle, group of axles and axle of a group taken individually). The minimum probability is a function of the test conditions (repeatability or reproducibility, environmental variability) and the sample size (see section 5.3 of the COST323 document). The statistical background and the origin of proof of the procedures and various formulas are presented in COST323 document.

*Table 91. Confidence interval width in different accuracy classes.*

| Type of measurement | Domain of use | Confidence interval width $\delta$(%) for Each Accuracy Class | | | | | |
|---|---|---|---|---|---|---|---|
| | | A (5) | B+ (7) | B (10) | C (15) | D (25) | E |
| **1. Gross weight** | greater than 35 kN | 5 | 7 | 10 | 15 | 25 | > 25 |
| **2. Group of axles** | greater than 20 kN | 7 | 10 | 13 | 18 | 28 | > 28 |
| **3. Single axle** | greater than 20 kN | 8 | 11 | 15 | 20 | 30 | > 30 |
| **4. Axle of a group** | greater than 20 kN | 10 | 15 | 20 | 25 | 35 | > 35 |
| | | | | | | | |
| **Speed** | greater than 30 km/h | 2 | 3 | 4 | 6 | 10 | > 10 |
| **Inter-axle distance** | | 2 | 3 | 4 | 6 | 10 | > 10 |
| **Axle/vehicle count** | | 1 | 1 | 1 | 3 | 5 | > 5 |

The full version of this document can be seen at:
http://dx.doi.org/10.1504/IJHVS.2000.004831

**B-WIM Accuracy**

From the above extract, the table specified above is still applicable to WIM systems today. In the initial concept, high numbers of vehicle runs were required due to inaccuracies in the systems used at that time. With the development of much more stable systems, and through experience, the number of calibration runs is now much lower, and a recommendation of 10 runs per lane is now acceptable. Factors such as pavement condition, dynamics in the bridge and variable speeds, have largely been eradicated by in-built compensation factors within the system software: including "bounce" (uneven pavement) where the initial impact of the 1st axle is distributed throughout the vehicle, temperature compensation factors and speed compensation factors.

The system generates an extremely high GVW accuracy with most results having an accuracy class of A5, the single axle accuracy is slightly lower, but by careful configuration and calibration, excellent results can also be achieved in this case as well. Below in figures 89 and 90 are eg. accuracy classes for Olhava and Äänekoski in 2016:

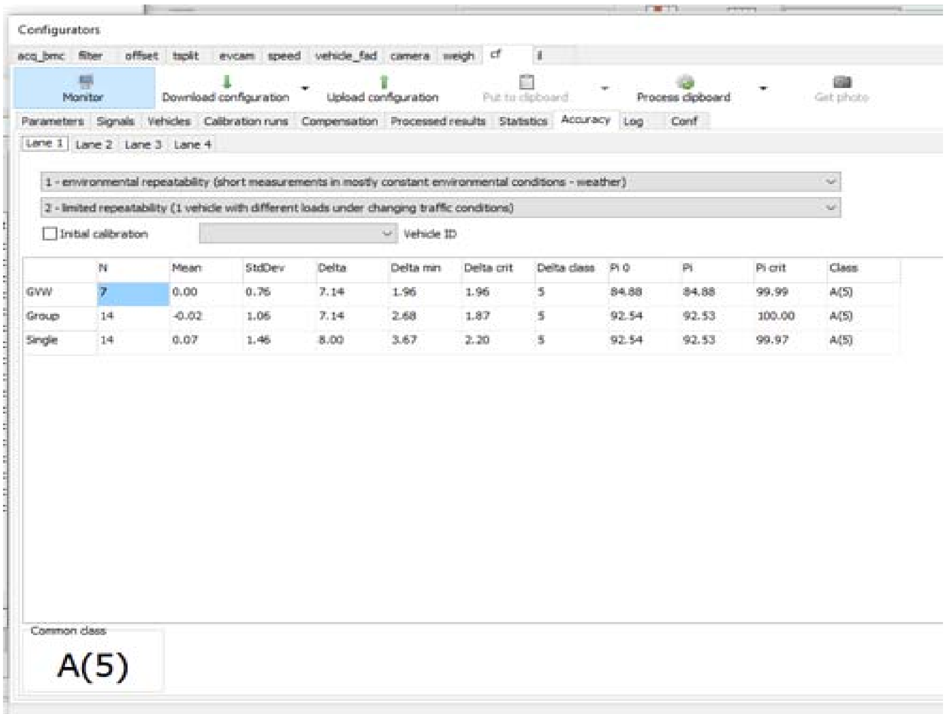



*Figure 89. Accuracy class calculation for Olhava bridge measurement 2016.*

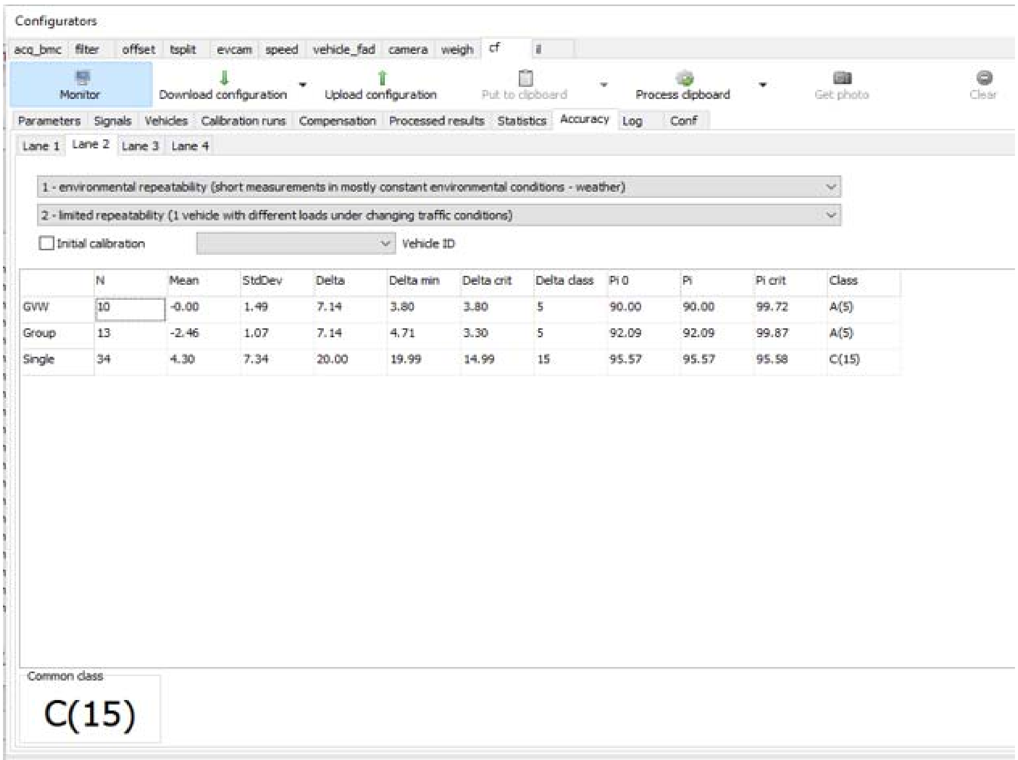



*Figure 90. Accuracy class calculation for Äänekoski bridge measurement 2016.*

# 5 Development of traffic conditions 2013–2017

## 5.1 General

In this section, we will review the effect of the implementation of the new traffic regulations and how vehicle configurations are changing as more haulage companies modify or purchase new trucks to benefit from the regulation changes.

**New vehicle regulation 2013**

The Finnish government increased the maximum permitted heavy vehicle weights in normal traffic from October 2013 with new regulation (Ajoneuvoasetus 2013). This decision differs from general European legislation (FinLex 4.12.1992/1257). The new regulation increased the maximum weight limit of trucks to 76 tons and the maximum height limit to 4.4 meters from the previous weight and height limits of the European modular system (60 tons and 4.2 meters), which were already in use in Finland. The new regulations affected vehicles which were already on the network and applied to all new vehicles. The new regulations do not force haulers to invest in new vehicles, but if they want to take advantage of bigger payloads, when using existing trucks, the new legislation requires an "alteration inspection" for the vehicle. The permanent changes in the weight limits of Finnish trucks are presented below:

- 4-axle truck without trailer 32 t  35 t (payload 18 t  21 t, +17%)
- 5-axle truck without trailer 38 t  42 t (payload 21 t  25 t, +19%)
- 8-axle vehicle combination 60 t  68 t (payload 37 t  45 t, +22%)
- 9-axle vehicle combination 60 t  76 t (payload 35 t  51 t, +46%)

In addition, the regulations include temporary weight increases which are in force until the end of April 2018. The temporary increases are presented below:

- 2-axle truck without trailer 18 t  20 t (payload 11 t  13 t, + 18%)
- 3-axle truck without trailer 26 t  28 t (payload 16 t  18 t, + 13%)
- 7-axle vehicle combination 60 t  64 t (payload 40 t  44 t, + 10%)

Furthermore, Finland has allowed operators to test even larger (up to 104 tons and 34,5 meters long) HCT vehicle combinations with exemption permissions on certain roads.

## 5.2 Vehicle classification

### 5.2.1 Vehicle Classification Olhava

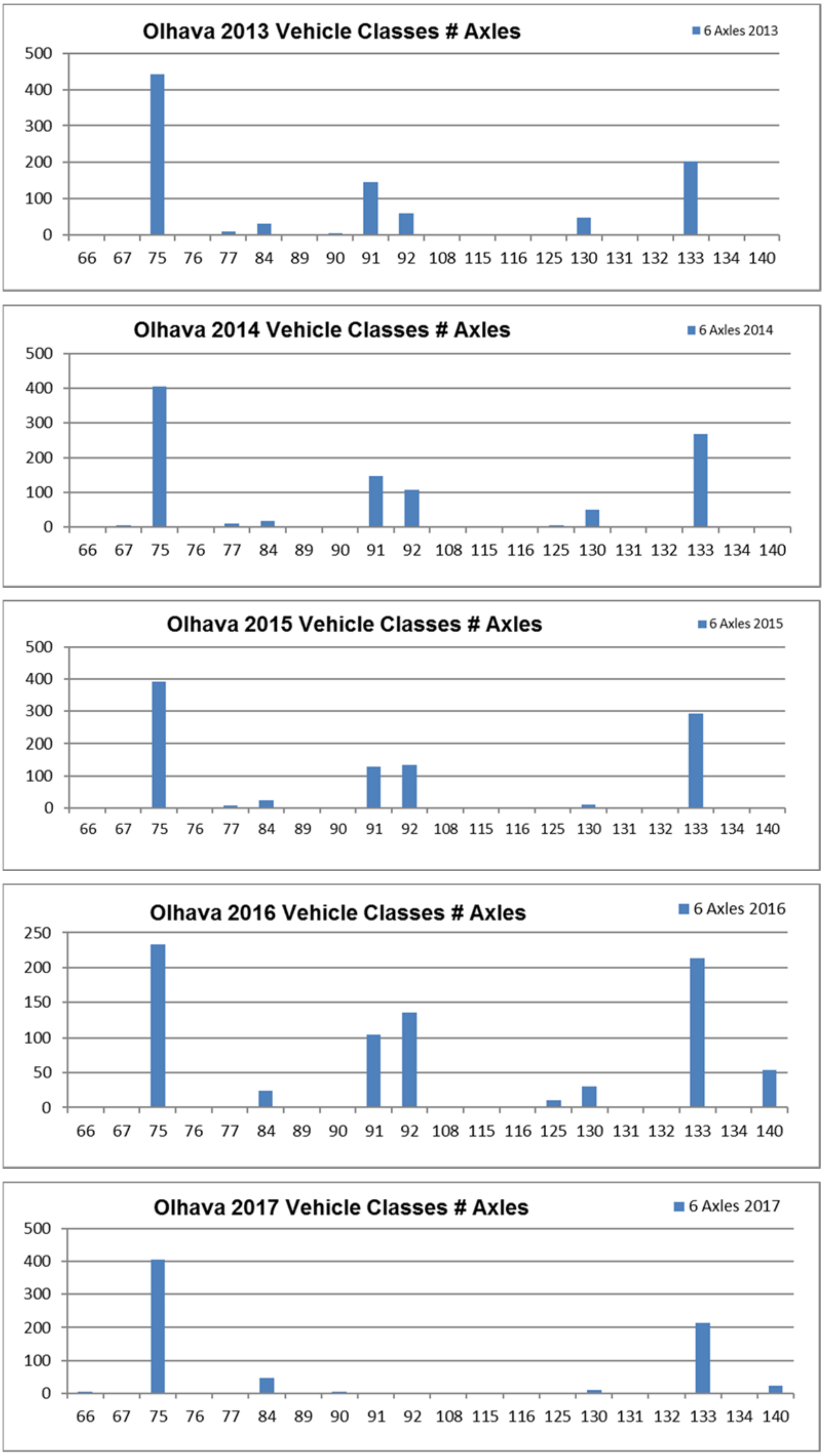
In the following figures, we have focused specifically on **Olhava**, as this bridge has been measured each year during the period 2013 - 2017. Tables 92 - 95 show classifications for all 6, 7, 8, 9 & 10+ axle vehicles, with the appropriate vehicle classes for each axle group.

**6 axle vehicles, Olhava measurements 2013 – 2017**

Vehicle volumes in different classes from Olhava measurements 2013-2017 are presented in figure 91 and the vehicle classification for 6 axle vehicles in table 92.

*Table 92. Classifications for vehicles with 6 axles.*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 66 | 6 |  | Min | 7.70 | 0.90 | 2.50 | 0.90 | 2.50 | 0.90 | | | | 519.93 |
| | | | | Max | 20.60 | 2.20 | 6.00 | 2.20 | 8.00 | 2.20 | | | | |
| 3 | 67 | 6 |  | Min | 12.40 | 0.90 | 2.80 | 3.90 | 3.90 | 0.90 | | | | 519.93 |
| | | | | Max | 23.40 | 2.20 | 5.00 | 7.00 | 7.00 | 2.20 | | | | |
| 3 | 75 | 6 |  | Min | 8.25 | 1.75 | 2.40 | 0.90 | 2.40 | 0.90 | | | | 519.93 |
| | | | | Max | 31.25 | 6.50 | 8.00 | 2.40 | 11.00 | 3.25 | | | | |
| 3 | 76 | 6 |  | Min | 9.70 | 2.20 | 2.40 | 0.90 | 2.40 | 1.75 | | | | 519.93 |
| | | | | Max | 30.30 | 6.50 | 8.00 | 2.40 | 11.00 | 2.40 | | | | |
| 3 | 77 | 6 |  | Min | 8.80 | 2.20 | 2.40 | 2.40 | 0.90 | 0.90 | | | | 519.93 |
| | | | | Max | 25.30 | 6.50 | 8.00 | 6.00 | 2.40 | 2.40 | | | | |
| 3 | 84 | 6 |  | Min | 11.60 | 2.50 | 1.25 | 6.00 | 0.90 | 0.90 | | | | 519.93 |
| | | | | Max | 22.90 | 7.00 | 2.40 | 10.00 | 1.75 | 1.75 | | | | |
| 3 | 89 | 6 |  | Min | 9.30 | 2.50 | 0.90 | 0.90 | 2.50 | 2.50 | | | | 519.93 |
| | | | | Max | 23.90 | 5.50 | 2.20 | 2.20 | 7.00 | 7.00 | | | | |
| 3 | 90 | 6 |  | Min | 10.30 | 2.20 | 0.90 | 2.40 | 2.40 | 2.40 | | | | 519.93 |
| | | | | Max | 28.70 | 7.00 | 2.40 | 8.30 | 6.00 | 6.00 | | | | |
| 3 | 91 | 6 |  | Min | 8.80 | 2.20 | 0.90 | 2.40 | 2.40 | 0.90 | | | | 519.93 |
| | | | | Max | 29.80 | 7.00 | 2.40 | 8.00 | 10.00 | 2.40 | | | | |
| 3 | 92 | 6 |  | Min | 8.20 | 2.20 | 0.90 | 2.40 | 0.90 | 1.75 | | | | 519.93 |
| | | | | Max | 30.80 | 7.00 | 2.40 | 9.00 | 2.40 | 10.00 | | | | |
| 3 | 108 | 6 |  | Min | 7.30 | 2.20 | 0.90 | 0.90 | 2.40 | 0.90 | | | | 519.93 |
| | | | | Max | 20.30 | 6.00 | 2.20 | 2.20 | 7.50 | 2.40 | | | | |
| 4 | 115 | 6 |  | Min | 7.95 | 2.20 | 2.00 | 1.25 | 1.25 | 1.25 | | | | 519.93 |
| | | | | Max | 18.20 | 5.00 | 6.00 | 2.40 | 2.40 | 2.40 | | | | |
| 4 | 116 | 6 |  | Min | 7.50 | 2.20 | 2.00 | 1.10 | 1.10 | 1.10 | | | | 519.93 |
| | | | | Max | 25.80 | 5.00 | 10.00 | 3.60 | 3.60 | 3.60 | | | | |
| 4 | 125 | 6 |  | Min | 9.50 | 0.90 | 2.00 | 0.90 | 2.20 | 3.50 | | | | 519.93 |
| | | | | Max | 24.30 | 2.60 | 6.00 | 2.20 | 6.50 | 7.00 | | | | |
| 4 | 130 | 6 |  | Min | 7.30 | 2.20 | 0.90 | 2.40 | 0.90 | 0.90 | | | | 519.93 |
| | | | | Max | 16.90 | 5.00 | 1.25 | 7.00 | 2.40 | 1.75 | | | | |
| 4 | 131 | 6 |  | Min | 7.70 | 2.20 | 0.90 | 2.40 | 0.90 | 1.25 | | | | 519.93 |
| | | | | Max | 16.40 | 4.00 | 1.25 | 7.00 | 2.40 | 1.75 | | | | |
| 4 | 132 | 6 |  | Min | 8.20 | 2.20 | 0.90 | 2.40 | 0.90 | 1.25 | | | | 519.93 |
| | | | | Max | 18.10 | 5.00 | 1.25 | 7.00 | 2.40 | 2.40 | | | | |
| 4 | 133 | 6 |  | Min | 7.70 | 2.20 | 1.25 | 2.40 | 0.90 | 0.90 | | | | 519.93 |
| | | | | Max | 18.10 | 5.00 | 2.40 | 7.00 | 2.40 | 1.75 | | | | |
| 4 | 134 | 6 |  | Min | 8.00 | 2.20 | 1.25 | 2.40 | 0.90 | 1.25 | | | | 519.93 |
| | | | | Max | 18.60 | 5.00 | 2.40 | 7.00 | 2.40 | 2.40 | | | | |

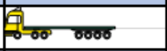


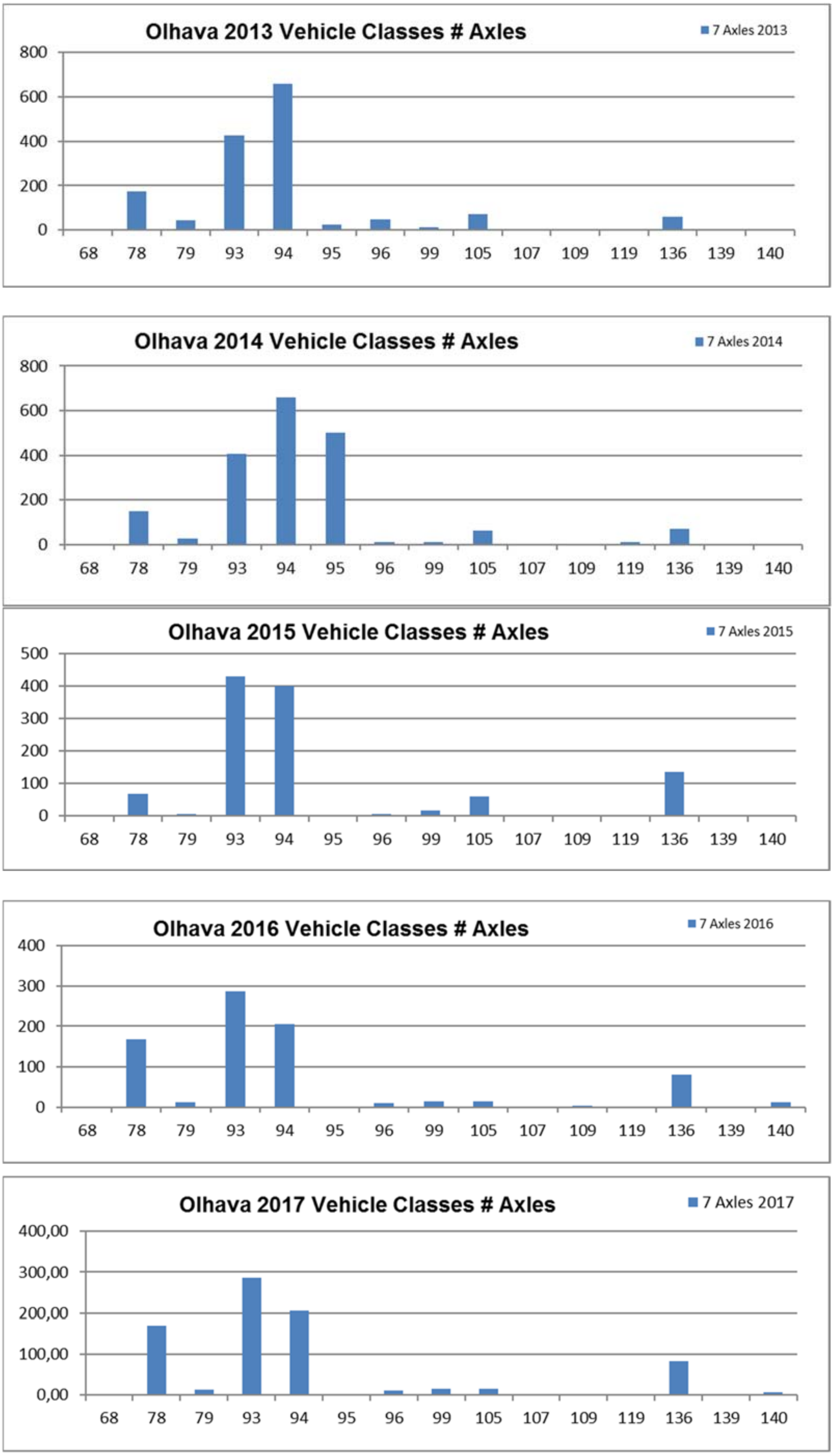

*Figures 91. Vehicle volumes in the different classes for 6 axle vehicles.*

**7 axle vehicles, Olhava measurements 2013 – 2017**

The vehicle classification for 7 axle vehicles in table 93 and vehicle volumes in different classes in figure 92.

*Table 93. Classifications for vehicles with 7 axles.*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 68 | 7 |  | Min | 13.30 | 0.90 | 2.80 | 3.90 | 0.90 | 3.90 | 0.90 | | | 588.6 |
| | | | | Max | 25.60 | 2.20 | 5.00 | 7.00 | 2.20 | 7.00 | 2.20 | | | |
| 3 | 78 | 7 |  | Min | 9.70 | 2.20 | 2.40 | 0.90 | 2.40 | 0.90 | 0.90 | | | 588.60 |
| | | | | Max | 27,7...29,7 | 6.50 | 8.00 | 2.40 | 6,0...8,0 | 2.40 | 2.40 | | | |
| 3 | 79 | 7 |  | Min | 11,2...9,7 | 2.20 | 2.40 | 0.90 | 2,4...0,9 | 2.40 | 0.90 | | | 588.60 |
| | | | | Max | 33,3...29,7 | 6.50 | 8.00 | 2.40 | 6,0...2,4 | 8.00 | 2.40 | | | |
| 3 | 93 | 7 |  | Min | 9.10 | 2.20 | 0.90 | 2.40 | 0.90 | 1.75 | 0.90 | | | 588.60 |
| | | | | Max | 33.60 | 7.00 | 2.40 | 9.00 | 2.40 | 11.00 | 1.75 | | | |
| 3 | 94 | 7 |  | Min | 9.90 | 2.20 | 0.90 | 2.40 | 0.90 | 1.75 | 1.75 | | | 588.60 |
| | | | | Max | 34.20 | 7.00 | 2.40 | 9.00 | 2.40 | 11.00 | 2.40 | | | |
| 3 | 95 | 7 |  | Min | 9.70 | 2.20 | 0.90 | 2.40 | 2.40 | 0.90 | 0.90 | | | 588.60 |
| | | | | Max | 30.10 | 7.00 | 2.40 | 9.00 | 8.00 | 2.40 | 1.25 | | | |
| 3 | 96 | 7 |  | Min | 10,1...7,7 | 2,2,,,1,0 | 0.90 | 2.40 | 2,4...1.6 | 0.90 | 1,25...0,9 | | | 588.60 |
| | | | | Max | 31.20 | 7.00 | 2.40 | 9.00 | 8.00 | 2.40 | 2.40 | | | |
| 4 | 99 | 7 |  | Min | 10.70 | 0.90 | 2.00 | 0.90 | 3.60 | 2.40 | 0.90 | | | 588.60 |
| | | | | Max | 27.40 | 2.40 | 4.20 | 2.40 | 8.00 | 8.00 | 2.40 | | | |
| | 105 | 7 |  | Min | 10.60 | 2.90 | 0.90 | 0.90 | 2.60 | 2.40 | 0.90 | | | 588.60 |
| | | | | Max | 23.20 | 4.40 | 2.20 | 2.20 | 6.00 | 6.00 | 2.40 | | | |
| | 107 | 7 |  | Min | 8.20 | 2.20 | 0.90 | 0.90 | 2.40 | 0.90 | 0.90 | | | 588.60 |
| | | | | Max | 20.40 | 5.00 | 2.20 | 2.20 | 7.00 | 2.00 | 2.00 | | | |
| | 109 | 7 |  | Min | 12.70 | 2.90 | 0.90 | 0.90 | 2.60 | 0.90 | 4.50 | | | 588.60 |
| | | | | Max | 25.60 | 4.80 | 2.20 | 2.20 | 6.00 | 2.40 | 8.00 | | | |
| | 119 | 7 |  | Min | 8.40 | 0.90 | 2.00 | 0.90 | 2.80 | 0.90 | 0.90 | | | 588.60 |
| | | | | Max | 23.10 | 2.40 | 5.50 | 2.40 | 8.00 | 2.40 | 2.40 | | | |
| 5 | 136 | 7 |  | Min | 6,7...6,5 | 2,2...2,0 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | | | 588.6 |
| | | | | Max | 26,6...42,0 | 5.50 | 2,4...2,8 | 9.50 | 2,8...9,8 | 2,8...8,8 | 3,6...5,6 | | | |
| | 139 | 7 |  | Min | 8.20 | 2.20 | 0.90 | 2.40 | 0.90 | 0.90 | 0.90 | | | 588.6 |
| | | | | Max | 37.30 | 7.00 | 2.40 | 9.00 | 2.40 | 11.00 | 5.50 | | | |

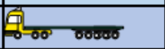
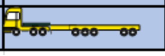


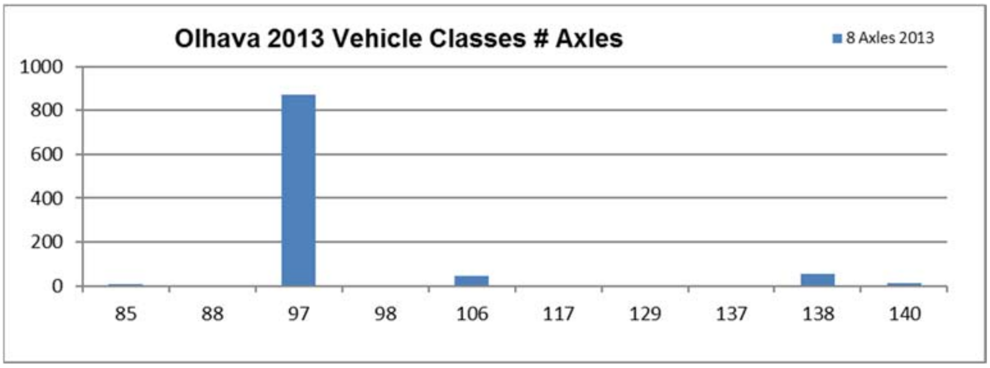

*Figures 92. Vehicle volumes in the different classes for 7 axle vehicles.*

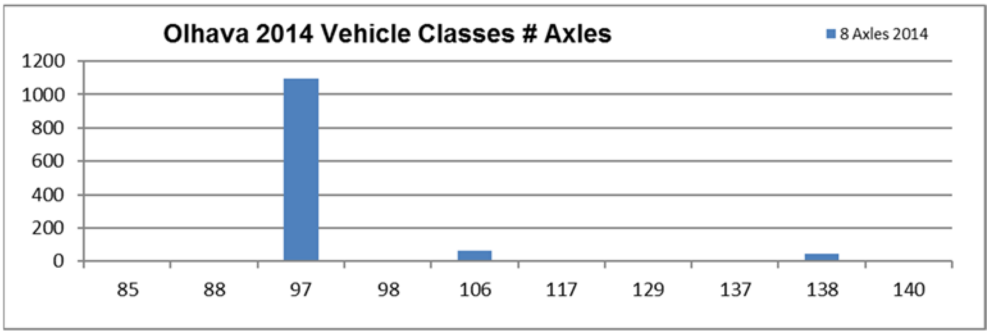
**8 axle vehicles, Olhava measurements 2013 – 2017**

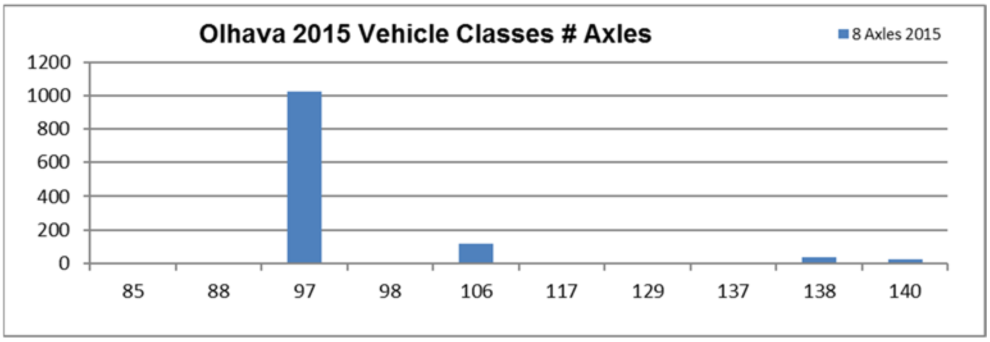
The vehicle classification for 8 axle vehicles in table 94 and vehicle volumes in different classes in figure 93.

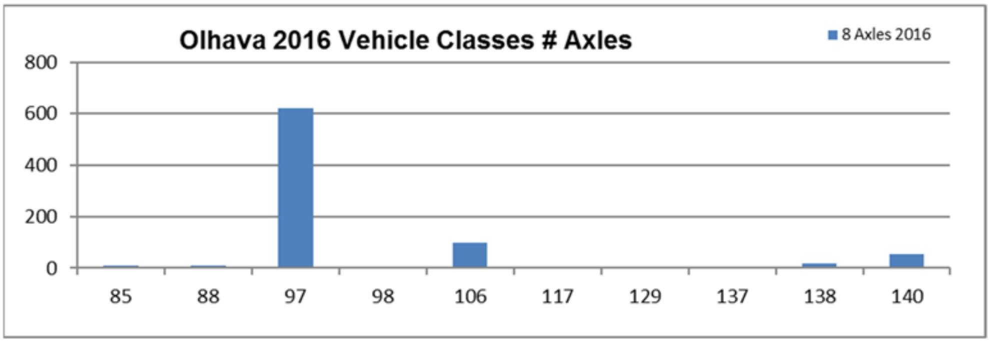
*Table 94. Classifications for vehicles with 8 axles.*

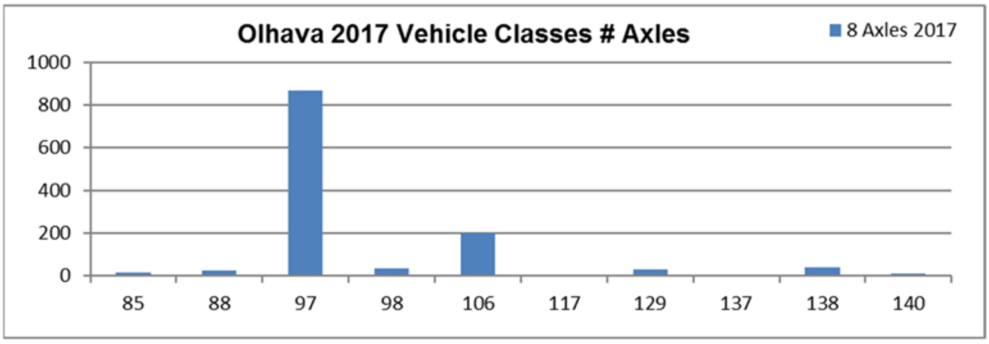
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 85 | 8 |  | Min | 14.40 | 0.90 | 2.20 | 0.90 | 3.60 | 0.90 | 5.00 | 0.90 | | 588.60 |
| | | | | Max | 33.40 | 2.20 | 6.00 | 2.40 | 9.00 | 2.40 | 9.00 | 2.40 | | |
| | 88 | 8 |  | Min | 14.20 | 0.90 | 2.80 | 0.90 | 3.90 | 0.90 | 3.90 | 0.90 | | 667.08 |
| | | | | Max | 27.80 | 2.20 | 5.00 | 2.20 | 7.00 | 2.20 | 7.00 | 2.20 | | |
| 3 | 97 | 8 |  | Min | 10.60 | 2.20 | 0.90 | 2.40 | 2,4...0,9 | 0,9...2,4 | 0.90 | 0.90 | | 667.08 |
| | | | | Max | 33.60 | 7.00 | 2.40 | 9.00 | 8...2,4 | 2,4...8,0 | 2.40 | 2.40 | | |
| 3 | 98 | 8 |  | Min | 10.60 | 2.20 | 0.90 | 2.40 | 0.90 | 2.40 | 0.90 | 0.90 | | 667.08 |
| | | | | Max | 33.60 | 7.00 | 2.40 | 9.00 | 2.40 | 8.00 | 2.40 | 2.40 | | |
| | 106 | 8 |  | Min | 13.70 | 2.90 | 0.90 | 0.90 | 3.20 | 0.90 | 4.00 | 0.90 | | 667.08 |
| | | | | Max | 29.70 | 5.50 | 2.00 | 2.40 | 6.00 | 2.40 | 9.00 | 2.40 | | |
| | 117 | 7 |  | Min | 14.30 | 2.90 | 0.90 | 0.90 | 2.60 | 6.10 | 0.90 | | | 667.08 |
| | | | | Max | 27.20 | 4.40 | 2.20 | 2.20 | 6.00 | 10.00 | 2.40 | | | |
| | 129 | 8 |  | Min | 14.40 | 3.30 | 3.90 | 0.90 | 0.90 | 3.60 | 0.90 | 0.90 | | 667.08 |
| | | | | Max | 25.75 | 6.10 | 5.80 | 2.00 | 2.00 | 5.85 | 2.00 | 2.00 | | |
| | 137 | 8 |  | Min | 9.10 | 2.20 | 0.90 | 2.40 | 0.90 | 0.90 | 0.90 | 0.90 | | 667.8 |
| | | | | Max | 29.40 | 5.50 | 2.40 | 9.50 | 2.80 | 2.80 | 3.60 | 2.80 | | |
| | 138 | 8 |  | Min | 10.70 | 2.20 | 0.90 | 2.40 | 0.90 | 0.90 | 2.50 | 0.90 | | 667.8 |
| | | | | Max | 32.10 | 5.20 | 2.40 | 9.50 | 2.80 | 2.80 | 6.60 | 2.80 | | |



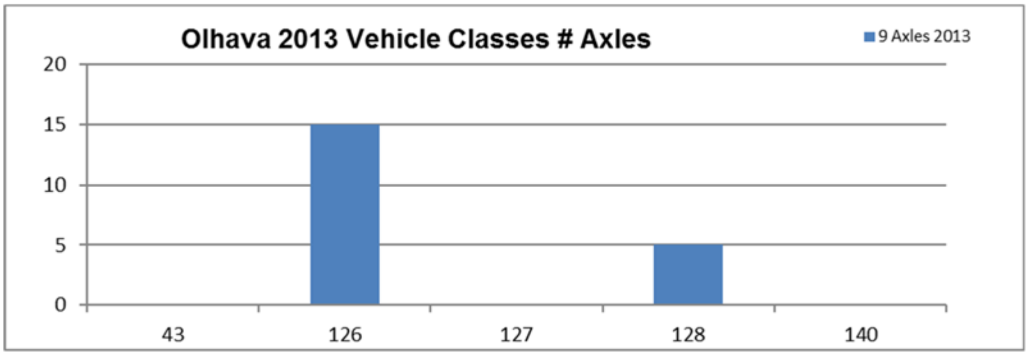

*Figures 93.* *Vehicle volumes in the different classes for 8 axle vehicles.*

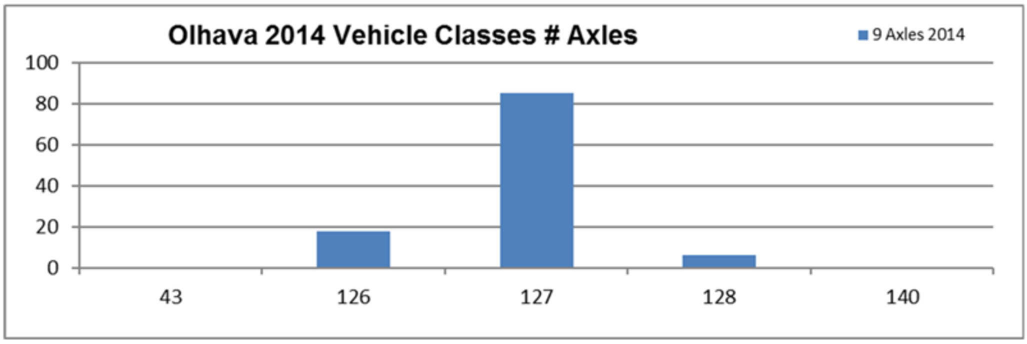
**9 axle vehicles, Olhava measurements 2013 – 2017**

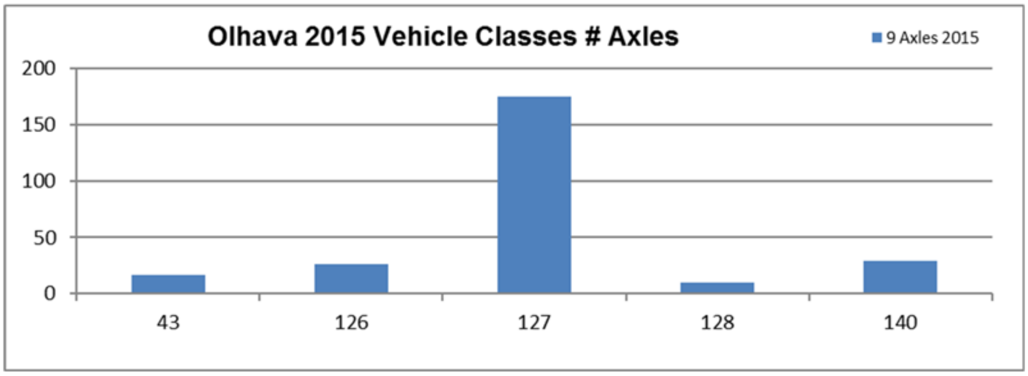
The vehicle classification for 9 axle vehicles in table 95 and vehicle volumes in different classes in figure 94.

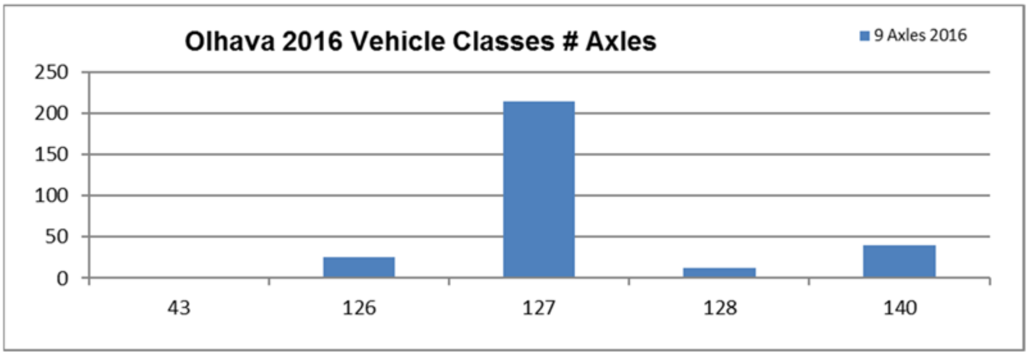
*Table 95. Classifications for vehicles with 9 axles.*

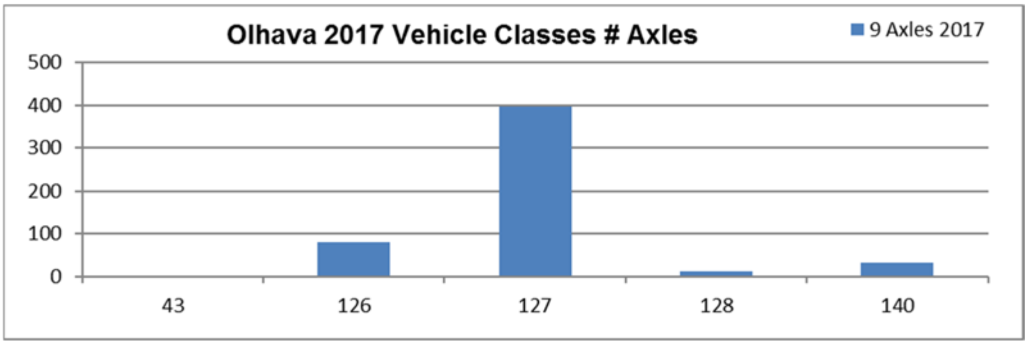
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 43 | 9 |  | Min | 6.40 | 2.20 | 1.25 | 2.00 | 0.90 | 3.60 | 0.90 | 0.90 | 0.90 | 745.56 |
| | | | | Max | 17.20 | 7.00 | 2.40 | 6.00 | 1.75 | 6.20 | 2.00 | 2.00 | 2.00 | |
| 3 | 126 | 9 |  | Min | 14.30 | 2.60 | 0.90 | 3.60 | 0.90 | 0.90 | 3.60 | 0.90 | 0.90 | 745.56 |
| | | | | Max | 29.90 | 5.10 | 2.00 | 6.50 | 1.90 | 1.90 | 8.90 | 1.80 | 1.80 | |
| 3 | 127 | 9 |  | Min | 13.40 | 2.60 | 0.90 | 0.90 | 3.20 | 0.90 | 3.10 | 0.90 | 0.90 | 745.56 |
| | | | | Max | 30.10 | 5.20 | 2.00 | 2.00 | 6.50 | 1.90 | 8.90 | 1.80 | 1.80 | |
| 3 | 128 | 9 |  | Min | 11.40 | 0.90 | 2.10 | 0.90 | 2.10 | 0.90 | 2.70 | 0.90 | 0.90 | 745.56 |
| | | | | Max | 30.00 | 2.10 | 5.50 | 2.00 | 6.00 | 1.90 | 8.90 | 1.80 | 1.80 | |



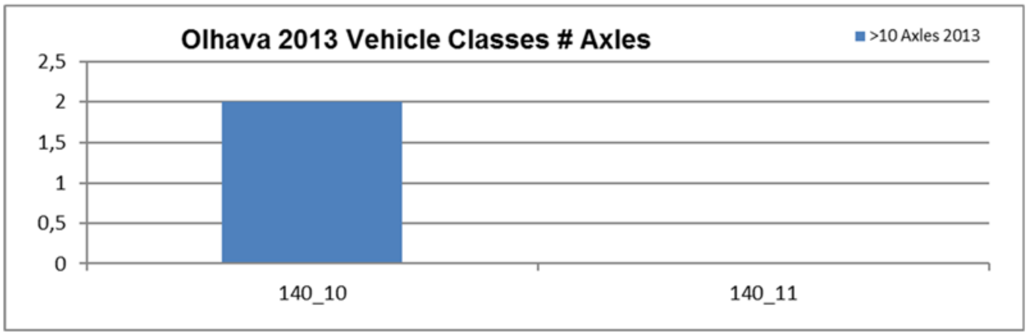


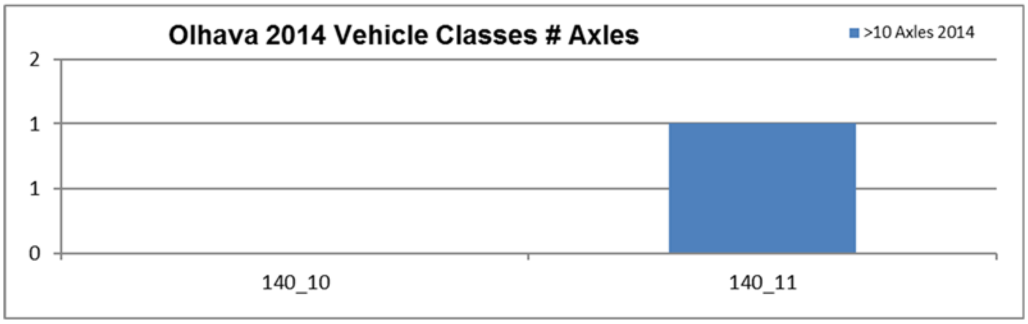



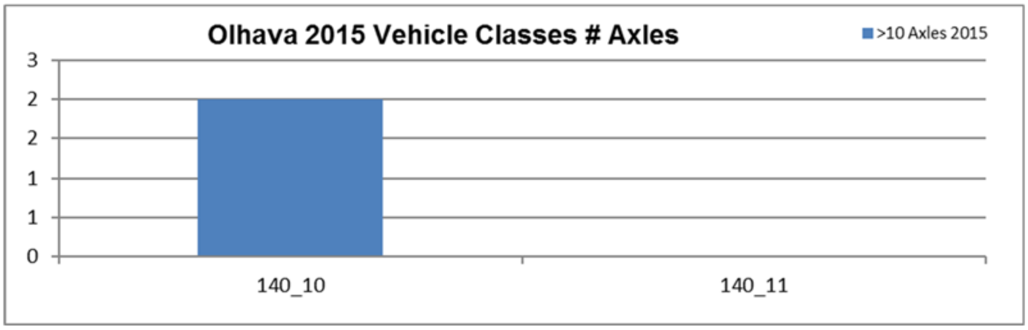

*Figures 94. Vehicle volumes in the different classes for 9 axle vehicles.*

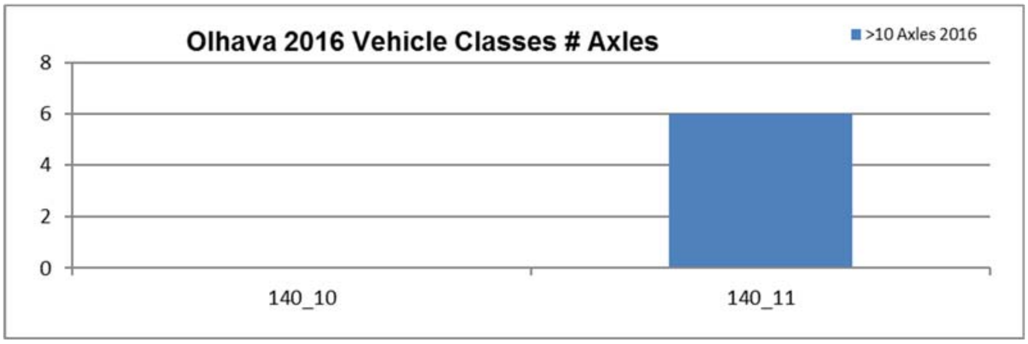
**≥ 10 axle vehicles, Olhava measurements 2013 – 2017**

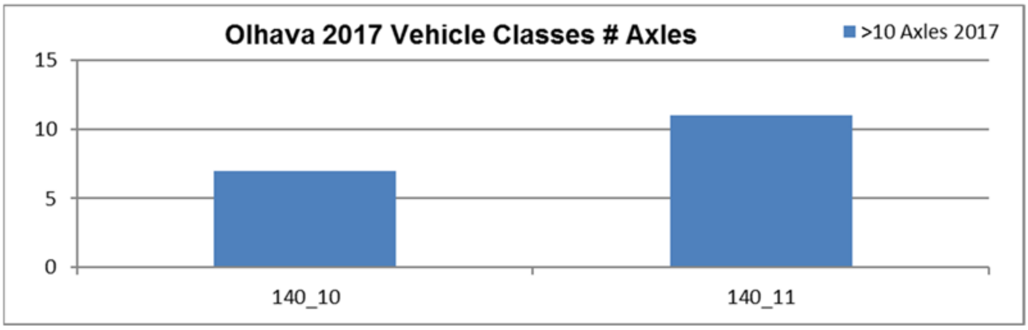
The classification table does not hold specifications for vehicles with 10 - 12 axles. The total numbers of 10 – 12 axle vehicles in Olhava measurements 2013 – 2017 are presented in figure 95.






*Figures 95. Vehicle volumes in the class 140 for vehicles having ≥10 axles.*

**Conclusions**

Although not conclusive, mainly because the traffic volume for 2016 is lower, it can be seen from the above diagrams and table 96 below, that the trending of the vehicle configuration is going towards multiple axles. This is especially significant with vehicle configurations with 9 axles, and noticeably as the vehicles with 6 and 7 axles reduce, vehicles with 8 & 9 axles increase. Maximum loads for 8 & 9 axle vehicles, depending on the tyre configurations, is 68t and 76t respectively.

*Table 96. Counted volumes for 6, 7, 8, 9 and ≥10 axle vehicles in Olhava 2013 - 2017.*

| | Vehicle Count Olhava | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Year 2013 | | Year 2014 | | Year 2015 | | Year 2016 | | Year 2017 | | |
| #Axles | Count | % | Count | % | Count | % | Count | % | Count | % | Trend +/- |
| 6 | 949 | 27,1 | 1024 | 24,0 | 1003 | 27,8 | 810 | 29,5 | 724 | 21,8 | ← |
| 7 | 1525 | 43,7 | 1903 | 44,7 | 1121 | 31,2 | 818 | 29,8 | 818 | 24,6 | ← |
| 8 | 996 | 28,5 | 1216 | 28,6 | 1225 | 33,9 | 813 | 29,7 | 1 245 | 37,4 | → |
| 9 | 20 | 0,57 | 109 | 2,6 | 257 | 7,1 | 293 | 10,7 | 521 | 15,6 | → |
| ≥10 | 2 | 0,06 | 1 | 0,02 | 2 | 0,06 | 6 | 0,21 | 18 | 0,54 | → |
| Total | 3 492 | 100,0 | 4 253 | 100,0 | 3 608 | 100,0 | 2 740 | 100,0 | 3 326 | 100,0 | |

The significance of this trend is threefold;

1) The total mass of the vehicle is increased, but if correctly loaded, this should have a limited impact on the infrastructure.

2) As the haulers can now increase their loadings and therefore minimize the number of runs required to deliver specific loads, an overall reduction in vehicles should be seen.

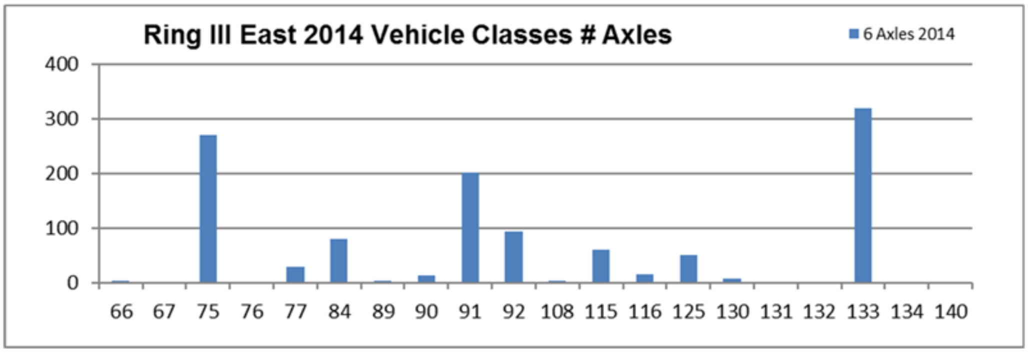
3) As the number of vehicles/journeys is reduced, there should be additional environmental improvements. For example, from emissions, but this is widely offset by the power requirements to move a heavier vehicle and that the footprint of the vehicle is increased due to the extra axles.

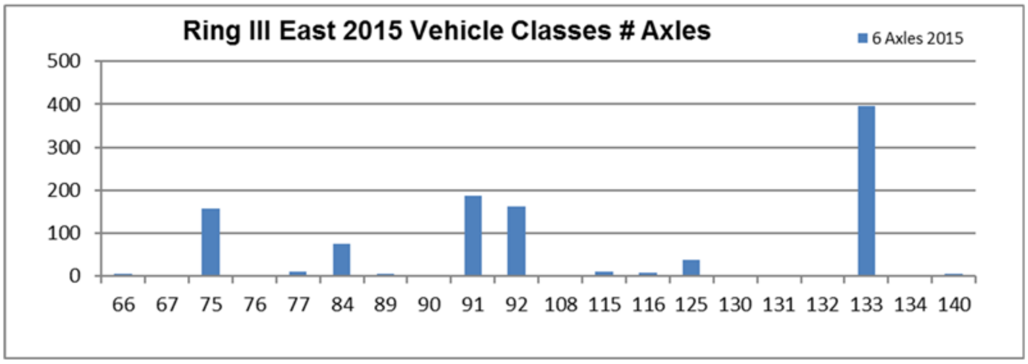
### 5.2.2 Vehicle classification Ring III East and West

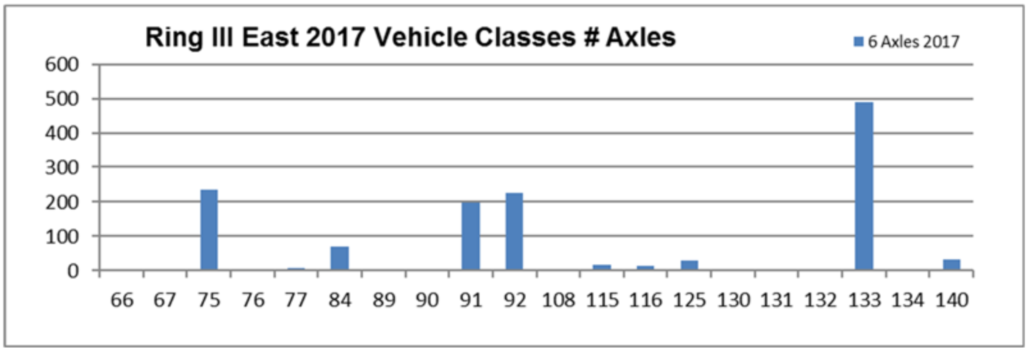
In the following figures, we have focused specifically on Ring III East & West, as this bridge has been measured in year 2014, 2015 & 2017. Tables 92 - 95 show classifications for all 6, 7, 8, 9 & 10+ axle vehicles, with the appropriate vehicle classes for each axle group.

**6 axle vehicles, Ring III East & West measurements 2014, 2015 & 2017**

Vehicle volumes in different classes from Ring III East & West measurements 2014, 2015 & 2017 are presented in figure 96 and the vehicle classification for 6 axle vehicles in table 92.



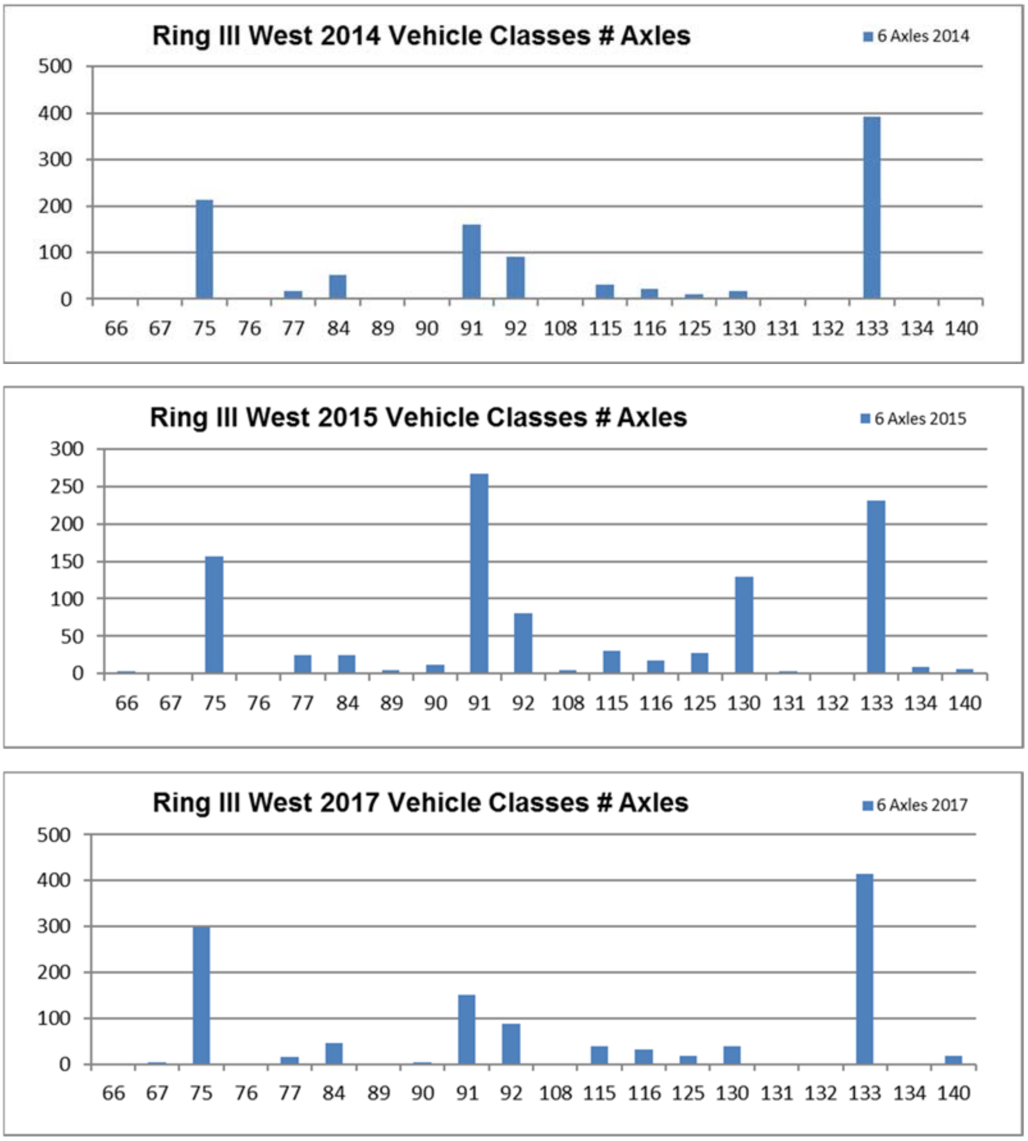
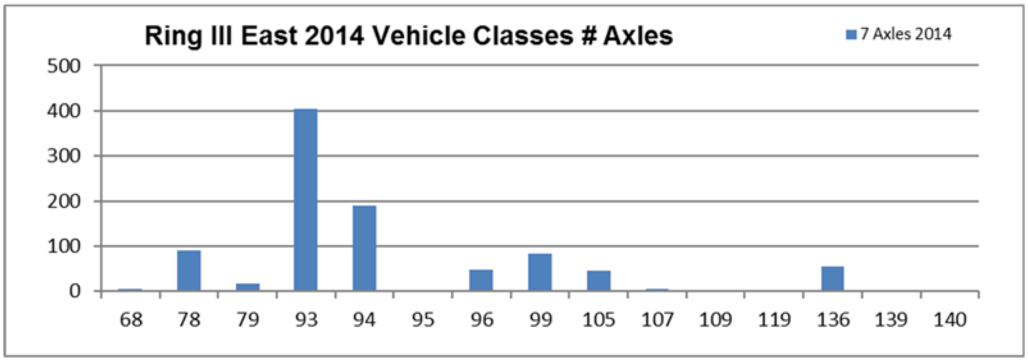
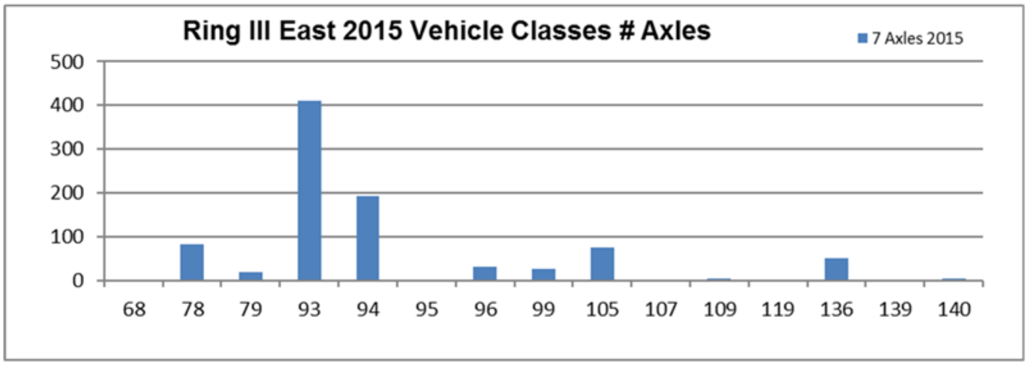


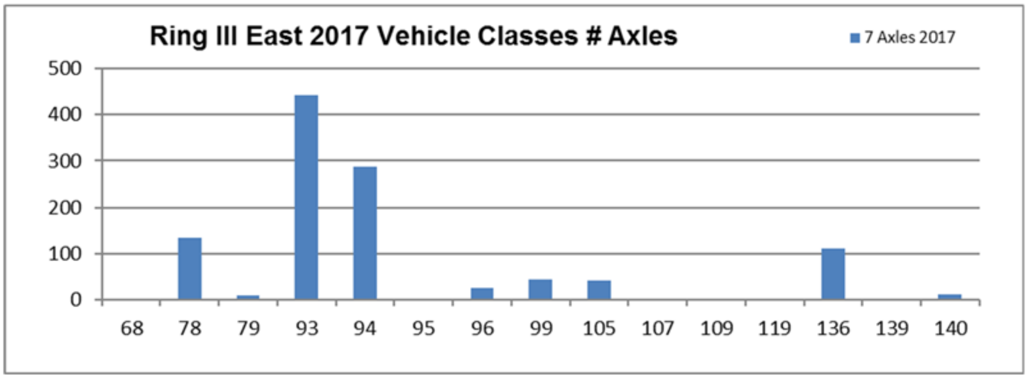

*Figure 96. Vehicle volumes in the different classes having 6 axles.*

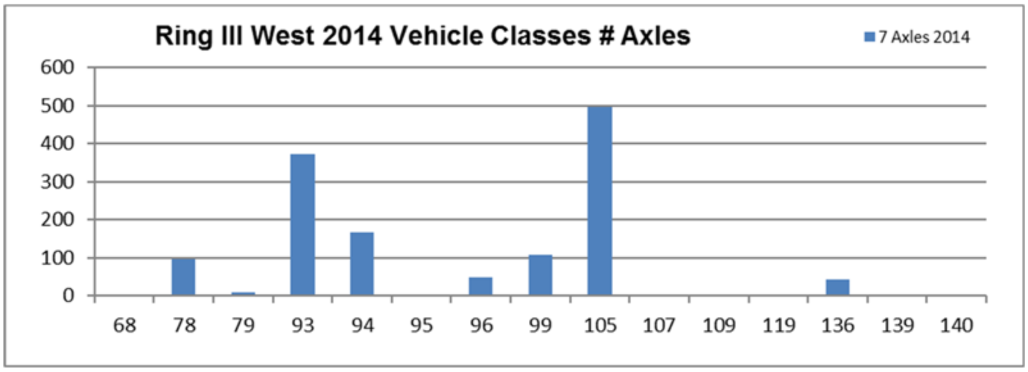
**7 axle vehicles, Ring III East & West measurements 2014, 2015 & 2017**

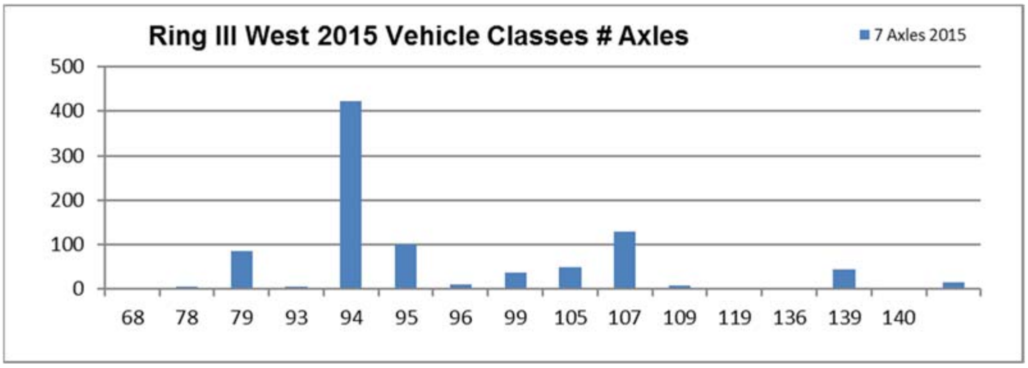
Vehicle volumes in different classes from Ring III East & West measurements 2014, 2015 & 2017 are presented in figure 97 and the vehicle classification for 7 axle vehicles in table 92.





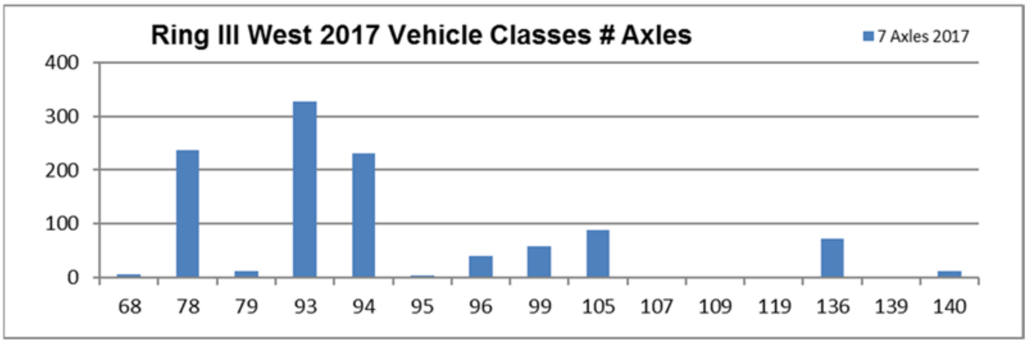
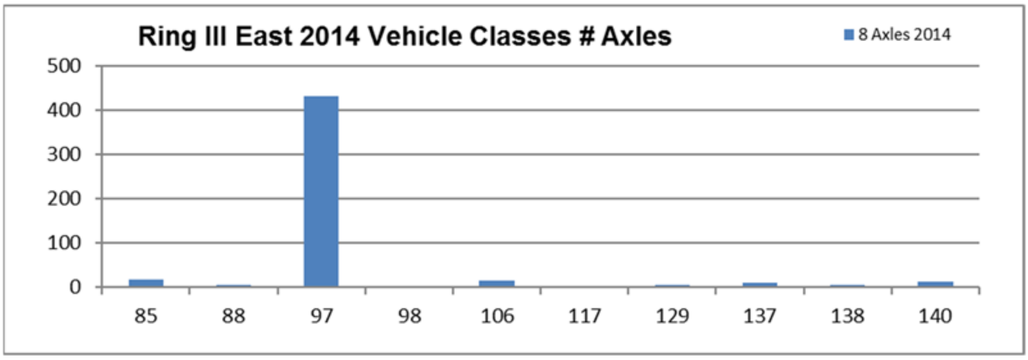
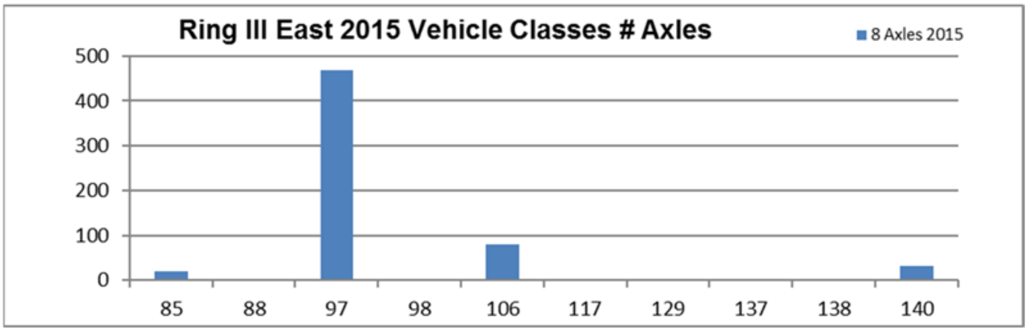



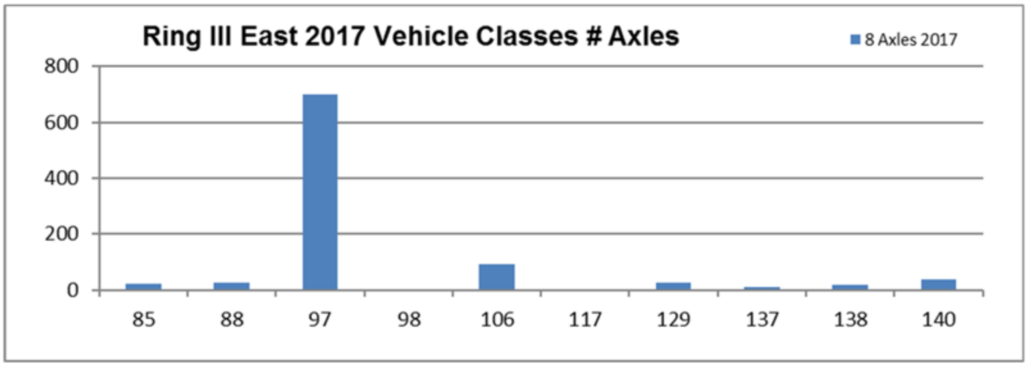

*Figure 97.* *Vehicle volumes in the different classes having 6 axles.*

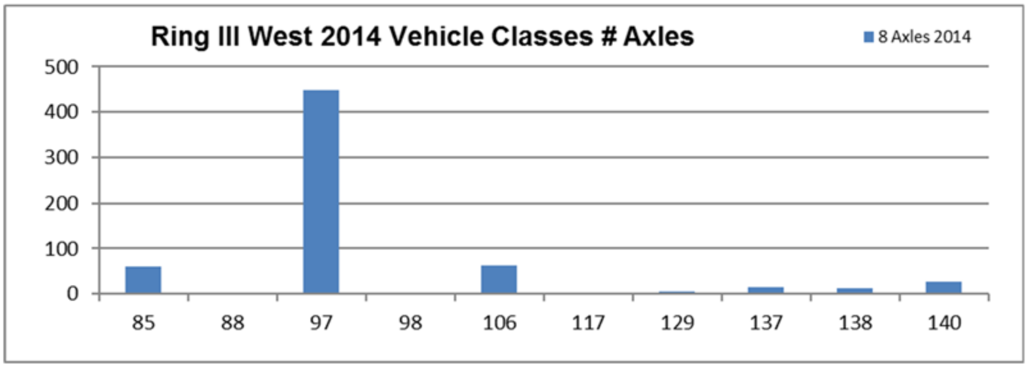
**8 axle vehicles, Ring III East & West measurements 2014, 2015 & 2017**

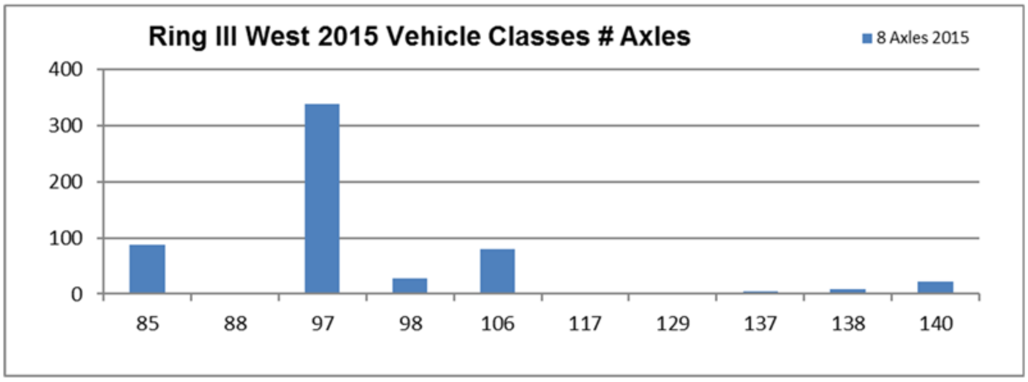
Vehicle volumes in different classes from Ring III East & West measurements 2014, 2015 & 2017 are presented in figure 98 and the vehicle classification for 8 axle vehicles in table 93.





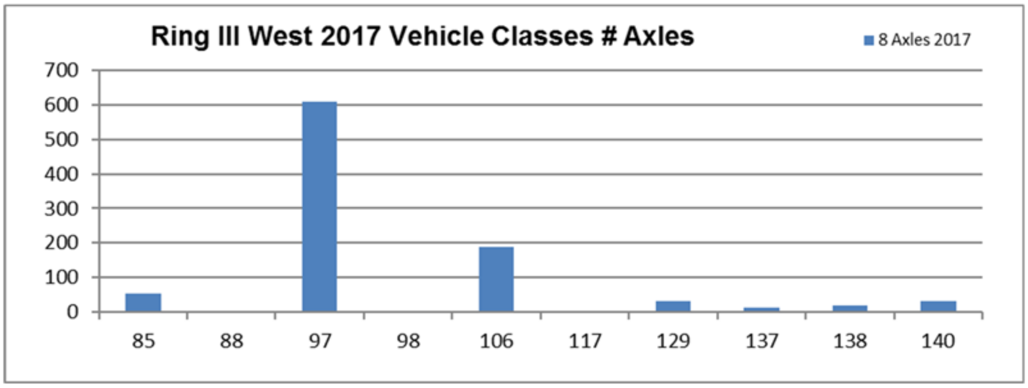
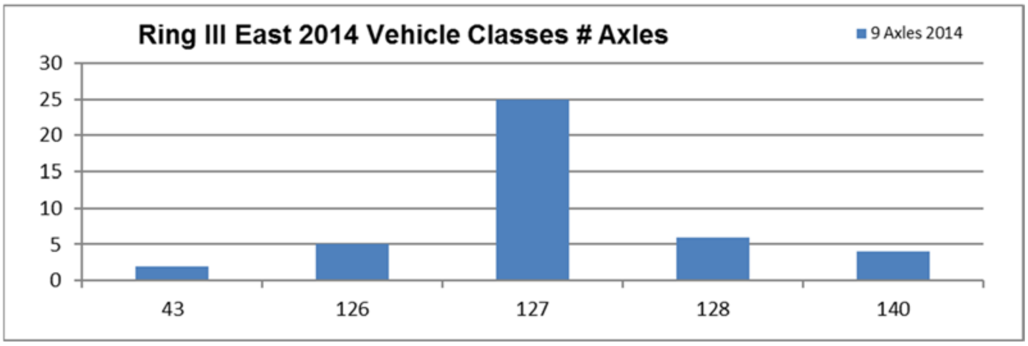
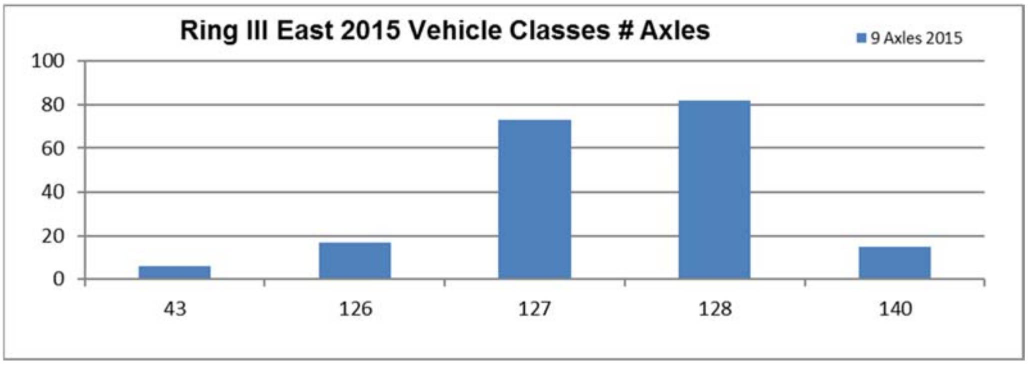



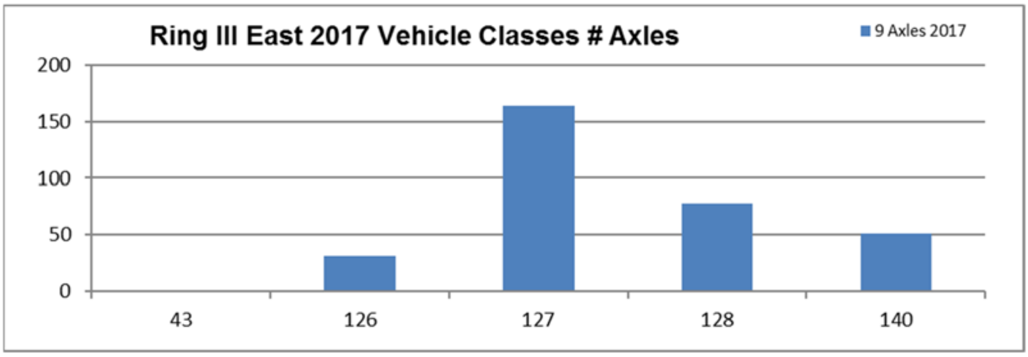

*Figure 98.* *Vehicle volumes in the different classes for 8 axle vehicles.*

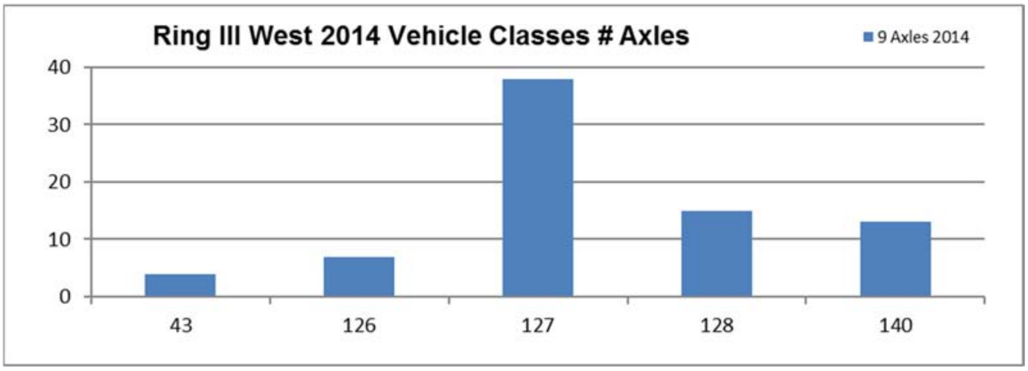
**9 axle vehicles, Ring III East & West measurements 2014, 2015 & 2017**

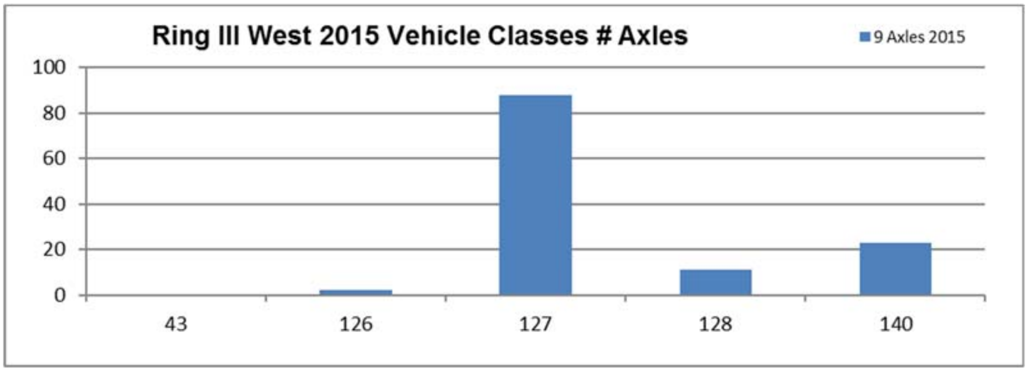
Vehicle volumes in different classes from Ring III East & West measurements 2014, 2015 & 2017 are presented in figure 99 and the vehicle classification for 9 axle vehicles in table 94.





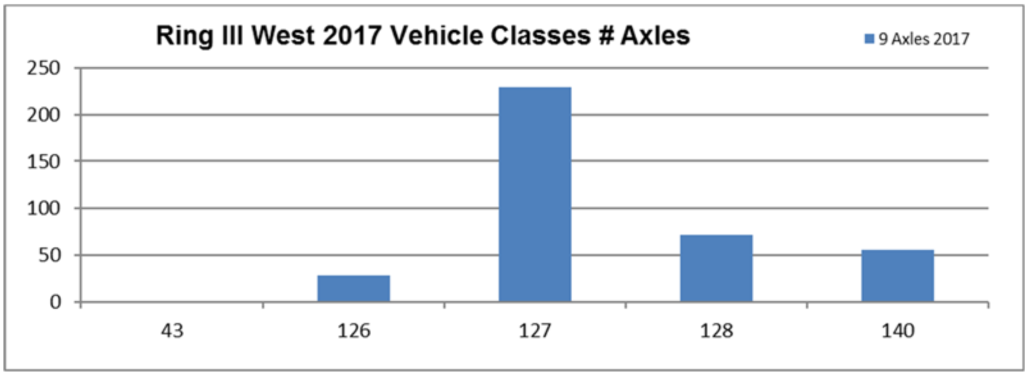
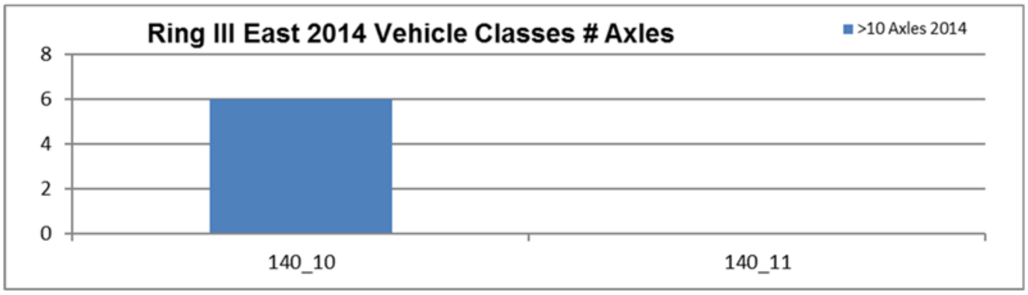
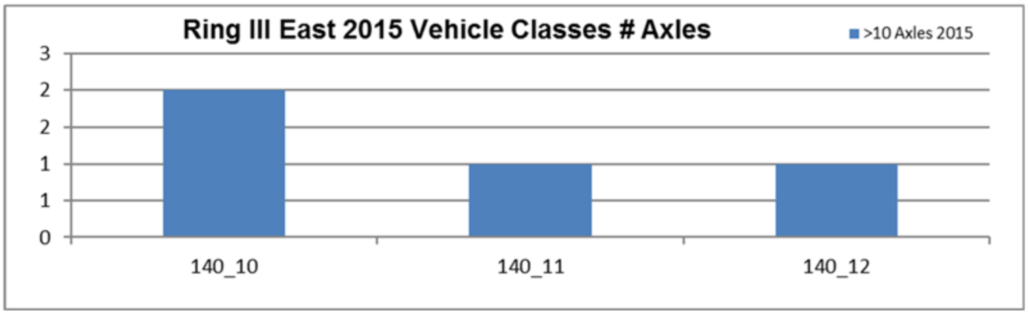




*Figure 99.* *Vehicle volumes in the different classes for 9 axle vehicles.*

**≥ 10 axle vehicles, Ring III measurements 2014, 2015 & 2017**

The classification table does not hold specifications for vehicles with 10 - 12 axles. The total numbers of 10 – 12 axle vehicles in Ring III measurements 2014, 2015 & 2017 are presented in figure 100.



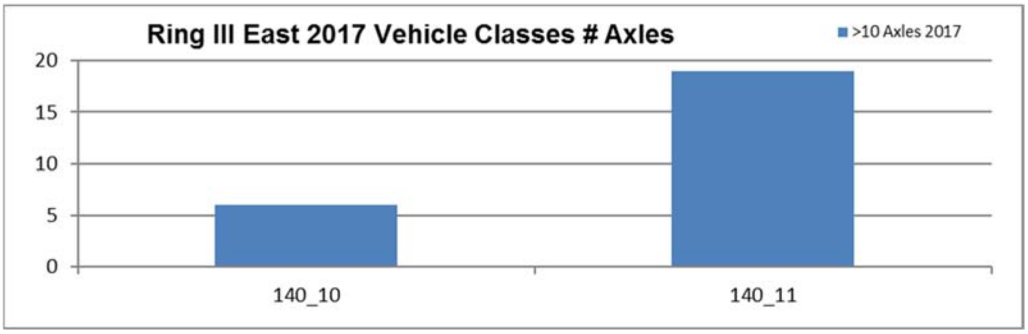



*Figure 100.* *Vehicle volumes in class 140 for >10 axle vehicles.*

**Conclusions**

As can be seen from diagrams above for Ring III and table below, that the trending of the vehicle configuration is going towards multiple axles. This is especially significant with vehicle configurations with 9 axles, and noticeably as the vehicles with 6 and 7 axles reduce, vehicles with 8 & 9 axles increase. Maximum loads for 8 & 9 axle vehicles, depending on the tyre configurations, is 68t and 76t respectively.

*Tables 97.* *Counted volumes for 6, 7, 8, 9 and ≥10 axle vehicles in Ring III East and West - 2014, 2015 and 2017.*

| | Vehicle Count Ring III East | | | | | | |
|---|---|---|---|---|---|---|---|
| | Year 2014 | | Year 2015 | | Year 2017 | | |
| **#Axles** | Count | % | Count | % | Count | % | Trend +/- |
| 6 | 1149 | 43,5 | 1065 | 38,4 | 1 332 | 35,6 | ← |
| 7 | 944 | 35,8 | 898 | 32,4 | 1 104 | 29,7 | ← |
| 8 | 497 | 18,8 | 610 | 22 | 925 | 24,9 | → |
| 9 | 42 | 1,6 | 193 | 7 | 324 | 8,7 | → |
| ≥10 | 6 | 0,02 | 4 | 0,014 | 25 | 0,67 | → |
| **Total** | 2 638 | 100 | 2 770 | 100 | 3 710 | 100 | |

| | Vehicle Count Ring III West | | | | | | |
|---|---|---|---|---|---|---|---|
| | Year 2014 | | Year 2015 | | Year 2017 | | |
| **#Axles** | Count | % | Count | % | Count | % | Trend +/- |
| 6 | 1017 | 33,0 | 1035 | 39,2 | 1 173 | 32,4 | ← |
| 7 | 1350 | 43,8 | 909 | 34,4 | 1 098 | 30,1 | ← |
| 8 | 633 | 20,5 | 571 | 21,6 | 947 | 26,1 | → |
| 9 | 77 | 2,5 | 124 | 4,7 | 383 | 10,6 | → |
| ≥10 | 5 | 0,02 | 1 | 0,014 | 23 | 0,63 | → |
| **Total** | 3 082 | 100,0 | 2 640 | 100,0 | 3 624 | 100,0 | |

The significance of this trend is threefold as for Olhava;

1) The total mass of the vehicle is increased, but if correctly loaded, this should have a limited impact on the infrastructure.

2) As the haulers can now increase their loadings and therefore minimize the number of runs required to deliver specific loads, an overall reduction in vehicles should be seen.

3) As the number of vehicles/journeys is reduced, there should be additional environmental improvements. For example, from emissions, but this is widely offset by the power requirements to move a heavier vehicle and that the footprint of the vehicle is increased due to the extra axles.

# 5.3 GVW

Although the primary object of this report is load distribution, there are many concerns about overloading. Overloads are shown above for each individual site, and noticeably, there is a variation from site to site, with in nearly all cases the axle overloads being significantly higher than GVW's. As the system accuracy class is generally A5, applying a filter of 5% determines that the vehicles marked as overloaded are above a 5% parameter tolerance. Of course, this filter can be raised to optimize fewer and fewer overloads, but there must be limits. Applying the new Finlex regulations, specifically on triple axles (from 24t to 27t) reduces axle overloading, but it must be stressed that even single axle overloads cause increased impact damages to the infrastructure. As we have seen earlier in this report, since the introduction of the new regulations, there has been a definite trend of higher average GVW's, but if vehicles are correctly loaded, this increase is not a specific problem. In fact, case studies have shown that by reducing the number of required journeys due to the increased payloads of vehicles, this has a positive effect both on the road network and environmentally.

Figure 101 shows the <u>total amount of axles for *n* axles per vehicle</u>, for **all measured sites each year combined**. Please note, that measurements have been on different locations and there have been less/more measurements performed each year, and this has an effect on the results.

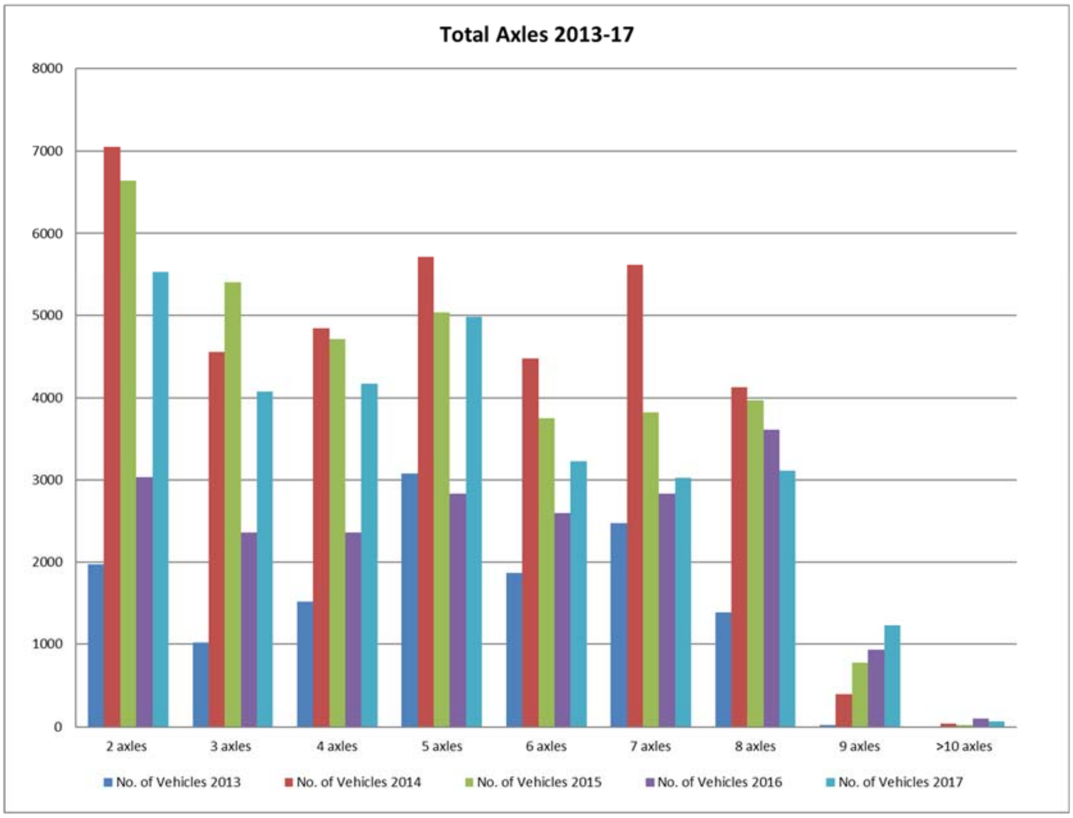



*Figure 101. Total amount of axles for n axles per vehicle, all measured sites each year combined.*

Figure 102 shows the <u>total amount of GVW for *n* axles per vehicle</u>, for **all measured sites each year combined**. Please note, that measurements have been on different locations and there have been less/more measurements performed each year, and this has an effect on the results.

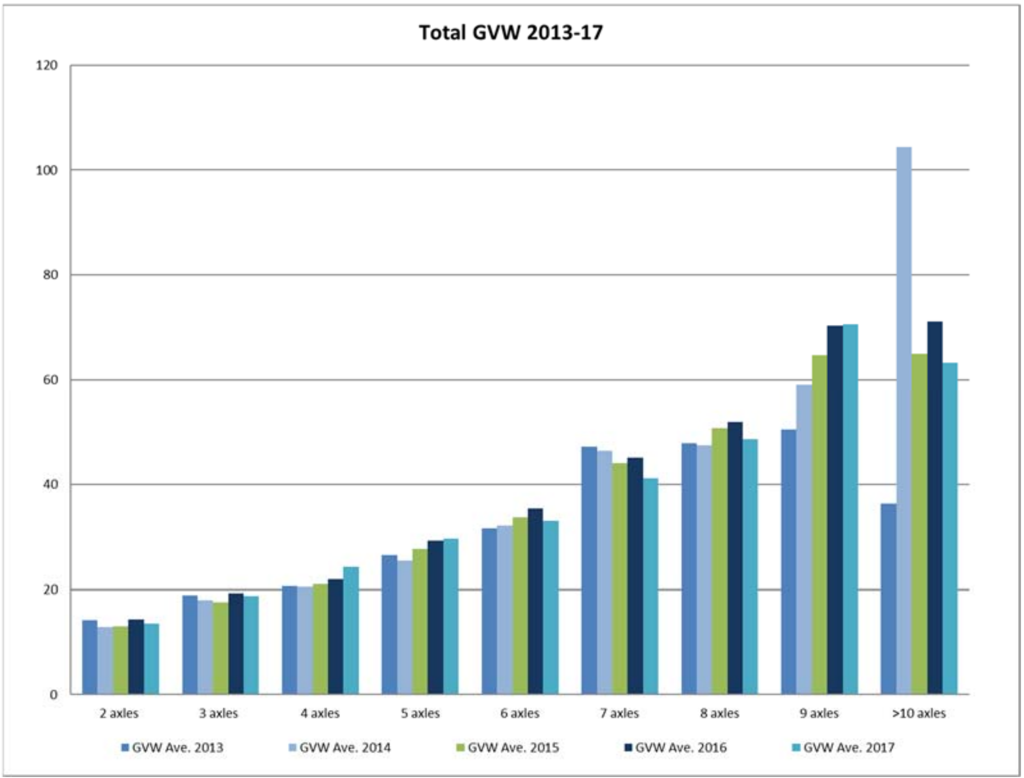



*Figure 102. Total amount of GVW for n axles per vehicle, all measured sites each year combined.*

As seen above there are very high GVW's for 10 axles. These are special transport vehicles on the measured site: Pirttikylä from 2014. When these special transports are excluded, we get figure 103 below, which is within expectation.

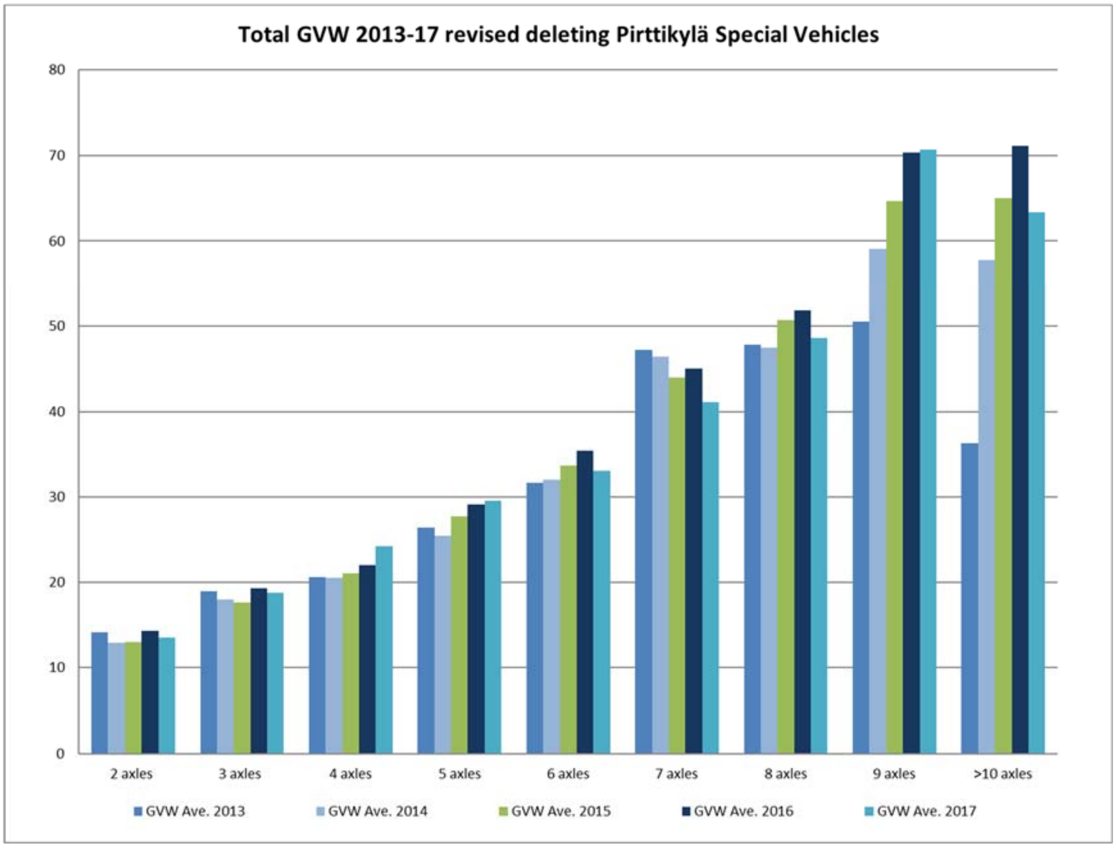



*Figure 103.* *Total amount of GVW for n axles per vehicle, for all measured sites each year combined, special transports excluded.*

# 5.4 Axle Analysis for Vehicles

This section gives extended information on GVW distribution within specific vehicle classes and then presents the average per axle(group). These groups are to be determined from the distribution curves produced from Olhava measurements 2013-2017. Presented in this report are 1-1-3 and 1-2-3 axle vehicles. Same kind of analysis has been made from Äänekoski bridge measurement results 2015.

The data has been extracted from the B-WIM measurement performed by Trafikia AB for The Finnish Transport Agency in September 2015. Some detailed information:

- The diagrams are self-explanatory and show the frequency of vehicles within an increasing 2-tonne range.
- The diagram has then been divided into suitable sectors to produce individual axle averages within each of these sectors. These averages are displayed in the tables.
- There is also a diagram and table which gives the summation of all vehicle classes analyzed.

Complimenting the earlier Olhava class distributions, the GVW distribution tables that follow are representing the individual axle groups i.e. 2, 3, 4, 5, 6, 7, 8, 9 & 10+ axles.

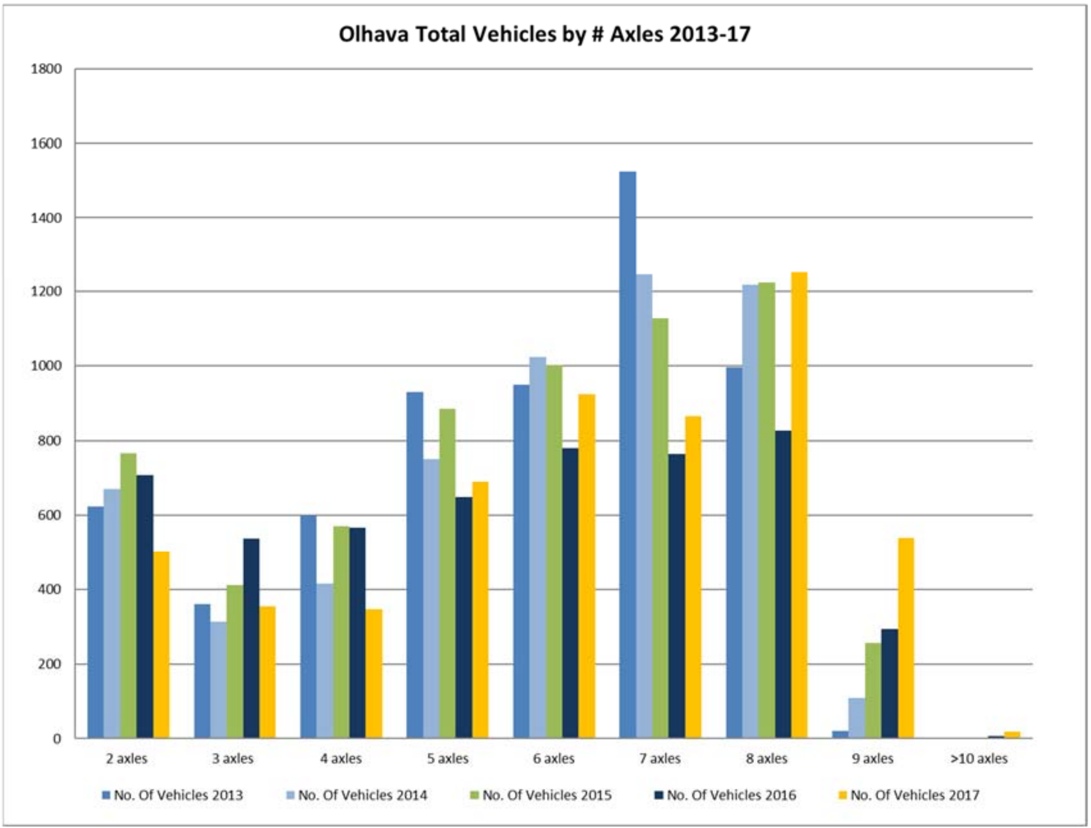



*Figure 104. Total amount of heavy vehicles for n axles per vehicle, measured in Olhava 2013-2017.*

Summarizing in figure 104 above, there is not a significant change in the number of total vehicles, but it can be noted that there is a shift from 7-axles towards 8 & 9 axles. However, since the new regulations were implemented, there has been a definite upward trend in the GVWs. This is very noticeable in the axle groups 8, 9 & 10+ where the AVERAGE GVW is over 50t, 60t and 70t for the respective groups. This change can be noted for all the measured sites, and the full tabulation for individual sites can be examined in the excel file found in the appendices.

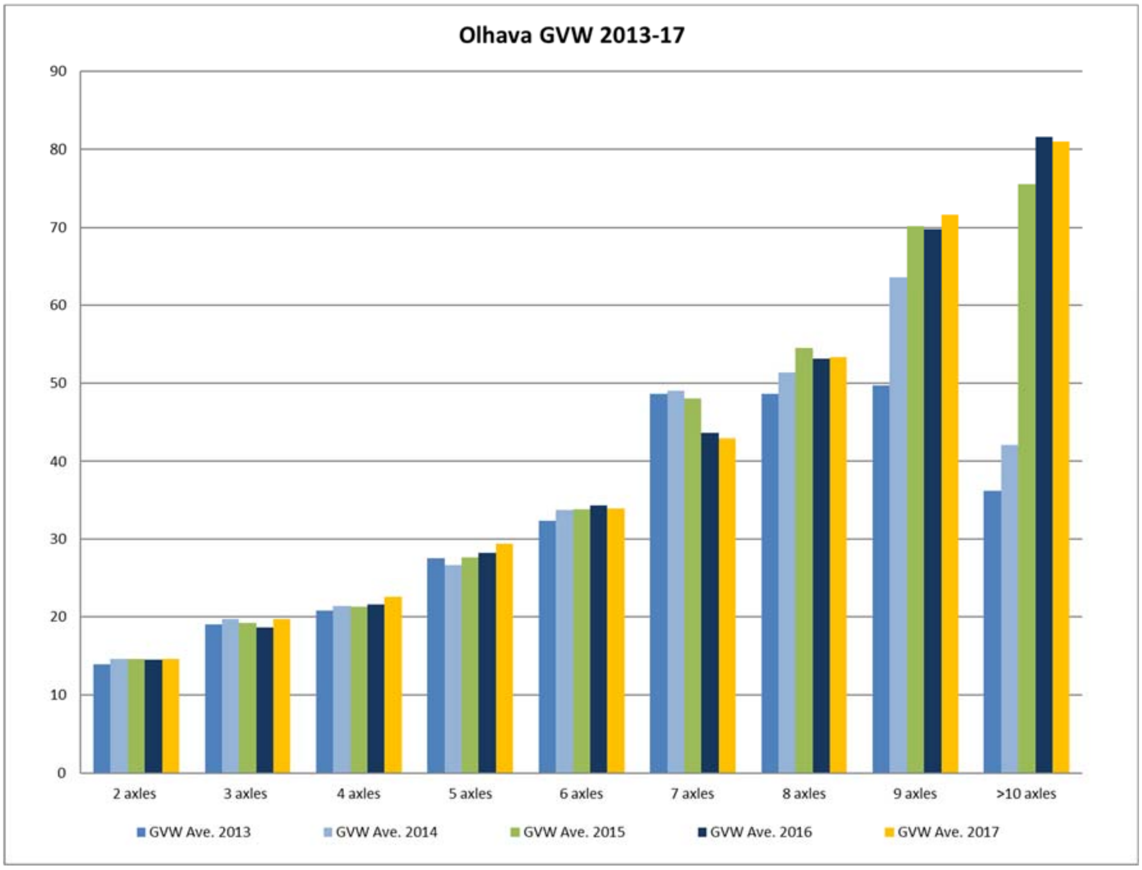


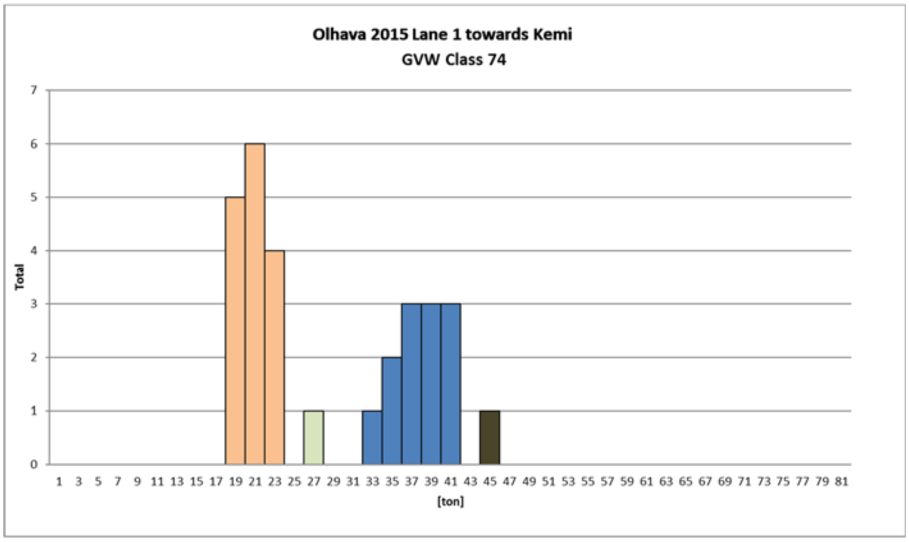

*Figure 105. Total amount of GVW for n axles per vehicle, measured in Olhava 2013-2017.*

### Axle Analysis for Vehicles with Axle Configurations of 1-1-3

Configurations for this type of vehicle are "Vehicle Classifications" 74, 110-114. There were only 3 incidences in classes 110, 111 and 112, so these have been excluded from the analysis.

*Table 98. Average axle weight per sector and totals class 74 (1-1-3) for lanes 1 and 2.*

| Average Axle Weight per Sector and Totals Class 74 (1-1-3) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Count | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 |
| Lane 1 | Sector 1 | 15 | 5.221151 | 7.986621 | 2.873288 | 2.89008 | 2.89008 |
| | Sector 3 | 12 | 7.752596 | 11.65638 | 9.029281 | 8.774352 | 9.187337 |
| | Total | 29 | 5.816426 | 8.882748 | 5.114369 | 4.932016 | 5.074424 |
| | | | | | | | |
| Lane 2 | Sector 1 | 53 | 5.635875 | 7.342265 | 2.735225 | 2.774975 | 2.726163 |
| | Total | 55 | 5.665191 | 7.442037 | 2.921413 | 2.959717 | 2.91268 |
| | | | | | | | |
| | Total All | 84 | 5.717403 | 7.939425 | 3.678505 | 3.64063 | 3.658997 |



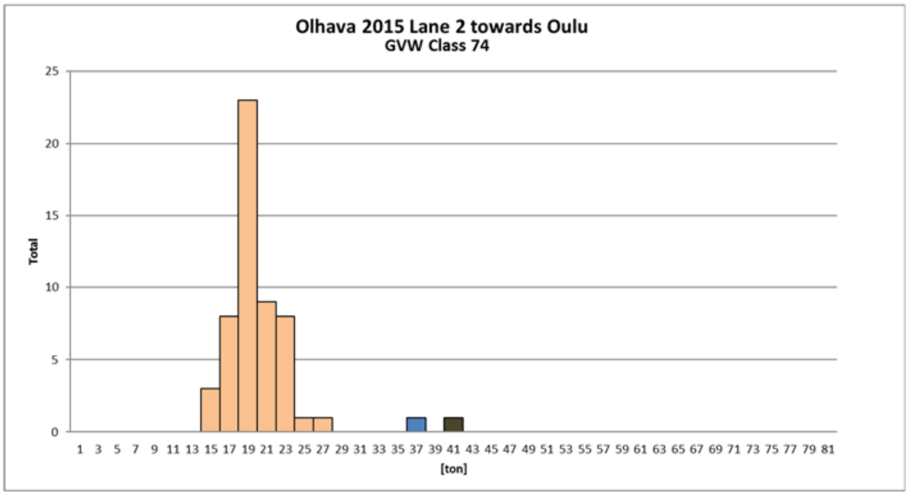
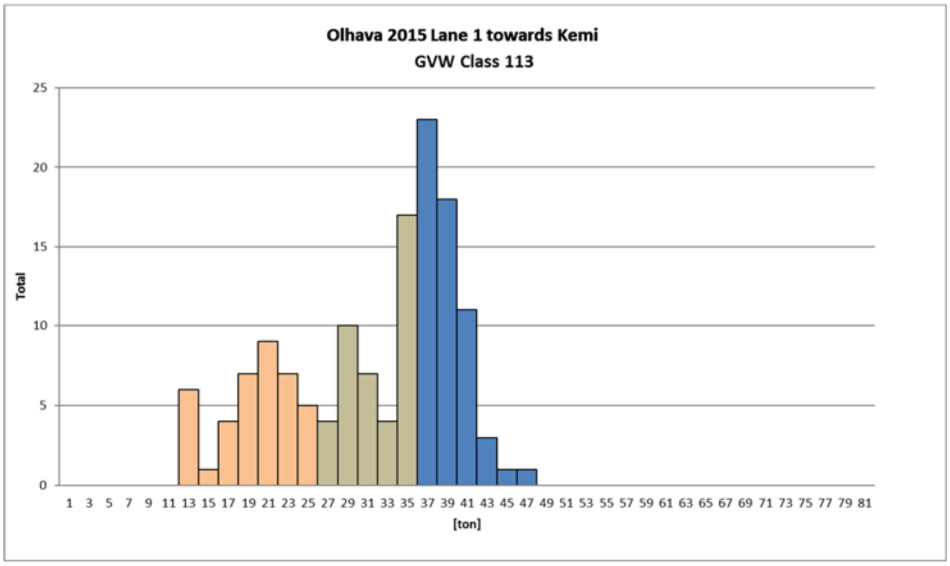




*Figure 106. GWV frequency of class 74 vehicles, lanes 1 and 2.*

*Table 99. Average axle weight per sector and totals class 113 (1-1-3) for lanes 1 and 2.*

| Average Axle Weight per Sector and Totals Class 113 (1-1-3) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Count | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 |
| Lane 1 | Sector 1 | 39 | 7.03884 | 5.385984 | 3.212106 | 3.212106 | 3.212106 |
| | Sector 2 | 42 | 5.456089 | 5.103874 | 3.045358 | 3.045358 | 3.045358 |
| | Sector 3 | 57 | 6.689964 | 9.696428 | 7.90976 | 7.847146 | 7.847146 |
| | Total | 138 | 6.402857 | 8.221521 | 5.978197 | 5.926472 | 5.926472 |
| | | | | | | | |
| Lane 2 | Sector 1 | 43 | 6.091097 | 4.63563 | 2.360833 | 2.360833 | 2.360833 |
| | Sector 2 | 46 | 6.501245 | 9.056698 | 6.054343 | 5.976756 | 5.976756 |
| | Sector 3 | 84 | 6.980868 | 10.36971 | 7.767943 | 7.567642 | 7.567642 |
| | Total | 173 | 6.632181 | 8.595353 | 5.96834 | 5.850454 | 5.850454 |
| | | | | | | | |
| | Total All | 322 | 6.307334 | 8.141509 | 5.768677 | 5.683173 | 5.683173 |



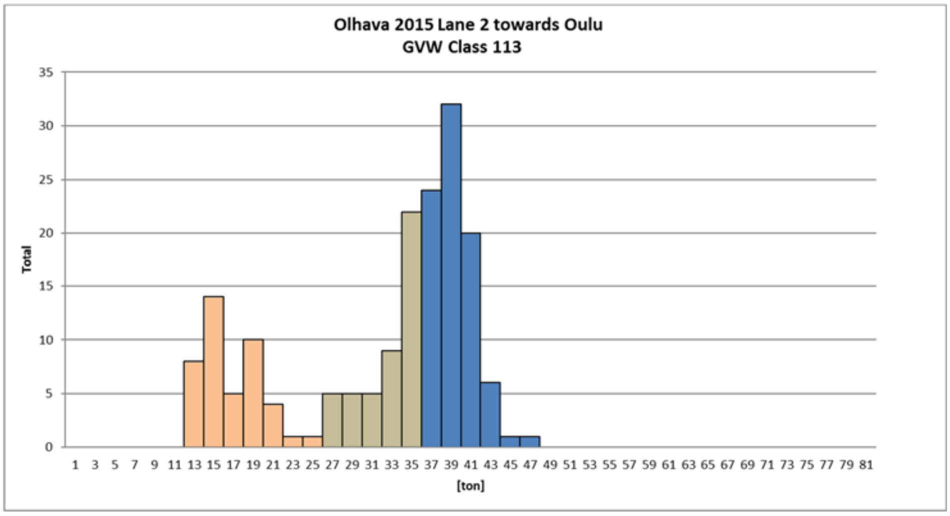
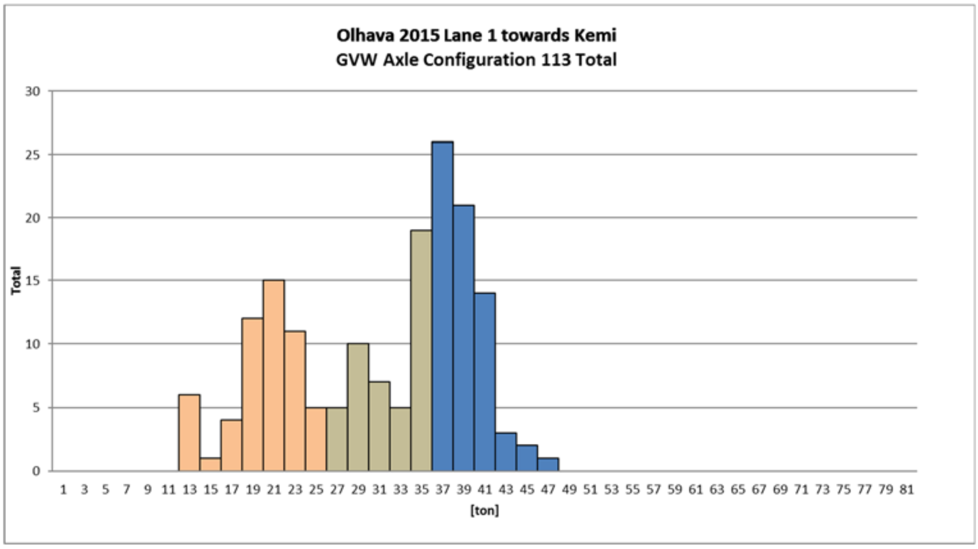




*Figure 107. GWV frequency of class 113 vehicles, lanes 1 and 2.*

*Table 100. Average axle weight per sector and totals axle configuration 1-1-3 for lanes 1 and 2.*

| Average Axle Weight per Sector and Totals Axle Configuration 1-1-3 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Count | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 |
| Lane 1 | Sector 1 | 54 | 5.667941 | 6.108383 | 3.11799 | 3.122654 | 3.122654 |
| | Sector 2 | 46 | 6.491846 | 8.937214 | 5.947583 | 5.836745 | 5.836745 |
| | Sector 3 | 67 | 6.680252 | 9.719478 | 7.930561 | 7.817434 | 7.879073 |
| | Total | 167 | 6.301022 | 8.336345 | 5.828191 | 5.753782 | 5.778512 |
| | | | | | | | |
| Lane 2 | Sector 1 | 84 | 6.617825 | 6.883789 | 2.890361 | 2.893736 | 2.893736 |
| | Sector 2 | 48 | 6.32872 | 8.892541 | 5.879004 | 5.842634 | 5.788738 |
| | Sector 3 | 86 | 6.968337 | 10.36311 | 7.769977 | 7.574333 | 7.574333 |
| | Total | 228 | 6.398916 | 8.317141 | 5.233336 | 5.153127 | 5.14178 |
| | | | | | | | |
| | Total All | 395 | 6.357528 | 8.32526 | 5.484831 | 5.407075 | 5.855277 |



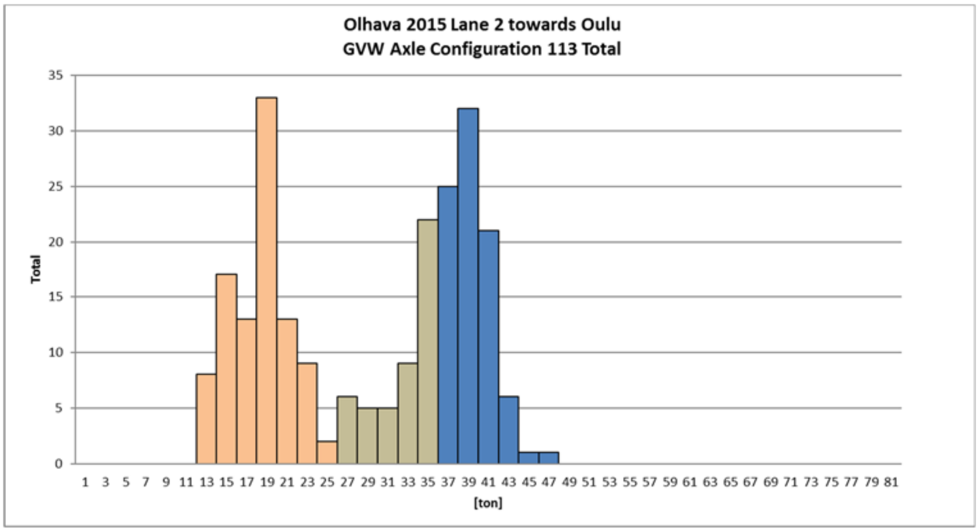



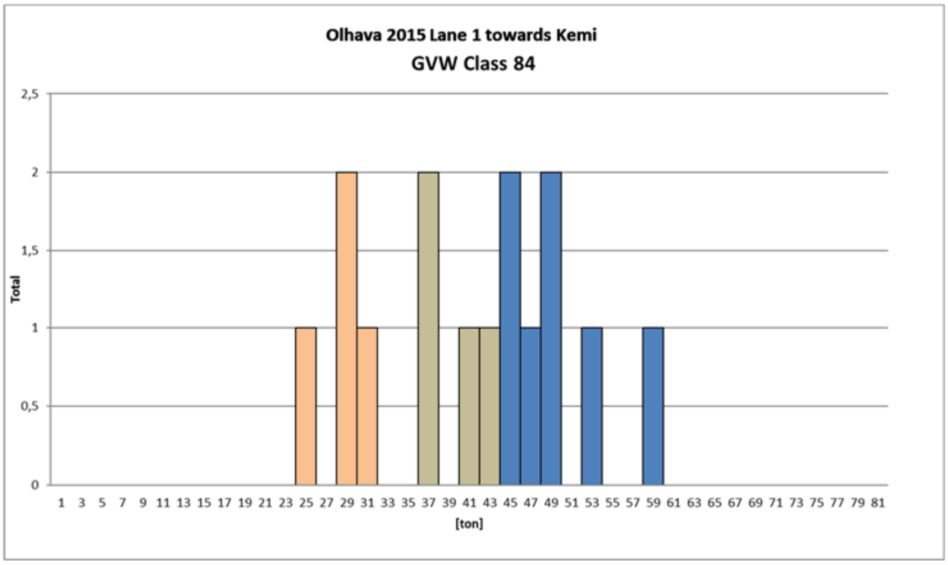

*Figure 108. GWV frequency of axle configuration 1-1-3 total, lanes 1 and 2.*

### Axle Analysis for Vehicles with Axle Configurations of 1-2-3

Configurations for this type of vehicle are "Vehicle Classifications" 84, 130-133. There were zero incidences in classes 131 and 132, so these have been excluded from the analysis.

*Table 101. Average axle weight per sector and totals class 84 (1-2-3) for lanes 1 and 2.*

| Average Axle Weight per Sector and Totals Class 84 (1-2-3) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Count | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 |
| Lane 1 | Sector 1 | 4 | 6.037485 | 5.091953 | 5.091953 | 4.515813 | 4.515813 | 4.515813 |
| | Sector 2 | 4 | 6.347733 | 7.019726 | 7.019726 | 6.451999 | 6.451999 | 6.451999 |
| | Sector 3 | 7 | 6.308547 | 9.344825 | 9.344825 | 8.329916 | 8.329916 | 8.329916 |
| | Total | 15 | 6.246714 | 7.590699 | 7.590699 | 6.812044 | 6.812044 | 6.812044 |
| | | | | | | | | |
| Lane 2 | Sector 1 | 3 | 6.486075 | 5.325978 | 5.325978 | 4.609457 | 4.609457 | 4.609457 |
| | Sector 2 | 3 | 6.099263 | 8.180503 | 8.180503 | 7.912658 | 7.912658 | 7.912658 |
| | Sector 3 | 2 | 8.008851 | 10.53673 | 10.53673 | 9.100967 | 9.100967 | 9.100967 |
| | Total | 8 | 6.721714 | 7.699112 | 7.699112 | 6.971035 | 6.971035 | 6.971035 |
| | | | | | | | | |
| | Total All | 23 | 6.411931 | 7.628408 | 7.628408 | 6.867345 | 6.867345 | 6.867345 |



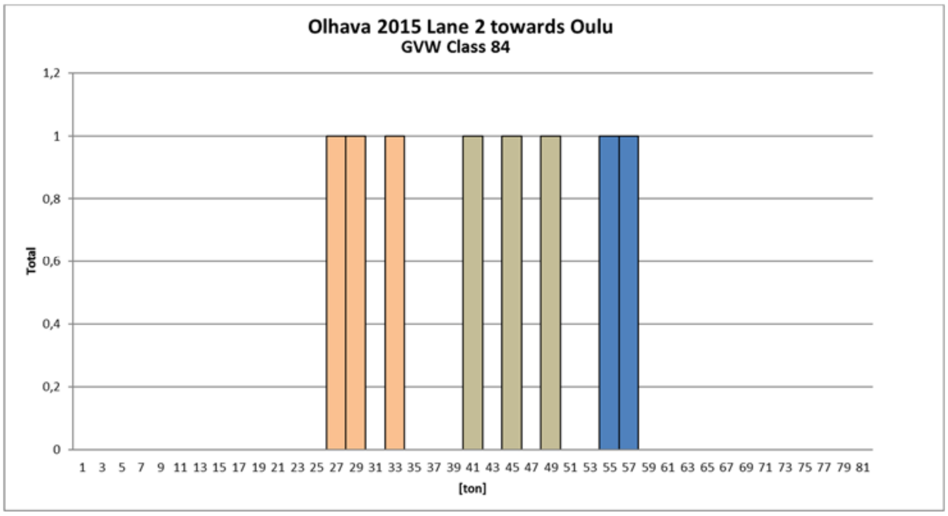
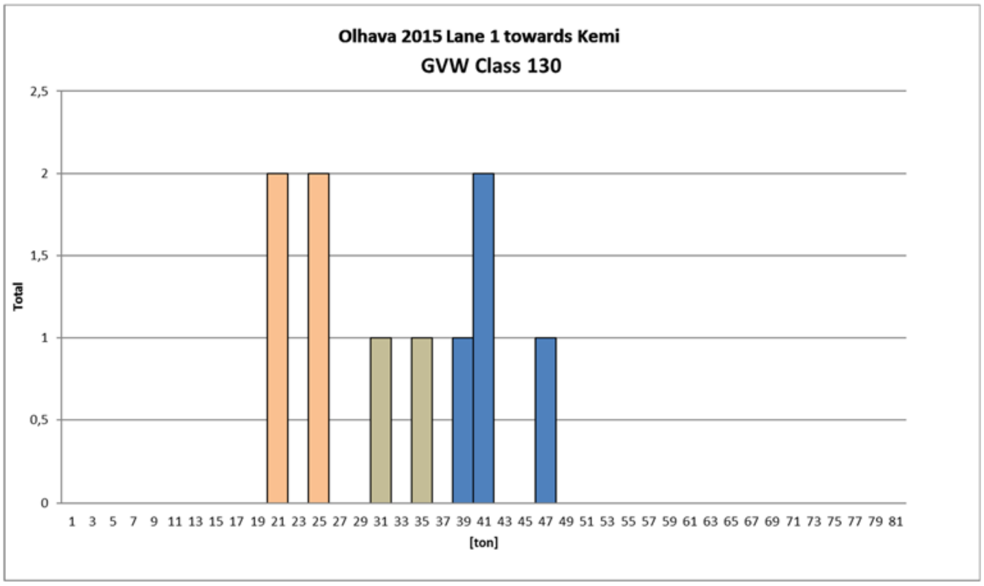




*Figure 109. GWV frequency of class 84 vehicles, lanes 1 and 2.*

*Table 102. Average axle weight per sector and totals class 130 (1-2-3) for lanes 1 and 2.*

| Average Axle Weight per Sector and Totals Class 130 (1-2-3) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Count | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 |
| Lane 1 | Sector 1 | 4 | 6.299552 | 3.572321 | 3.572321 | 3.414265 | 3.414265 | 3.414265 |
| | Sector 2 | 2 | 5.831757 | 4.702931 | 4.702931 | 6.024993 | 6.024993 | 6.024993 |
| | Sector 3 | 4 | 6.586092 | 6.976643 | 6.976643 | 7.531114 | 7.531114 | 7.531114 |
| | Total | 10 | 6.320609 | 5.160172 | 5.160172 | 5.58315 | 5.58315 | 5.58315 |
| | | | | | | | | |
| Lane 2 | Sector 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sector 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sector 3 | 1 | 7.381726 | 8.468743 | 8.468743 | 8.182203 | 8.182203 | 8.182203 |
| | Total | 1 | 7.381726 | 8.468743 | 8.468743 | 8.182203 | 8.182203 | 8.182203 |
| | | | | | | | | |
| | Total All | 11 | 6.417074 | 5.460951 | 5.460951 | 5.819428 | 5.819428 | 5.819428 |



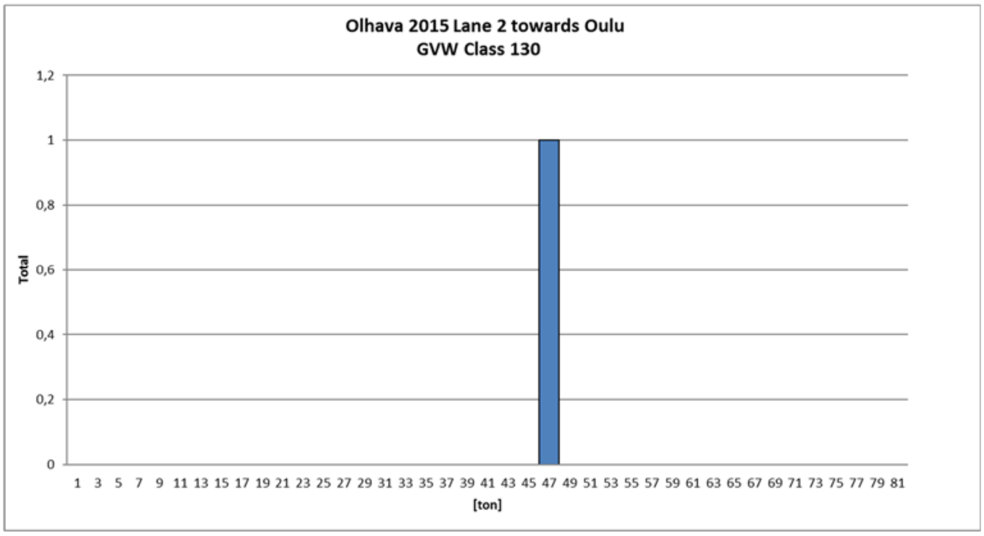
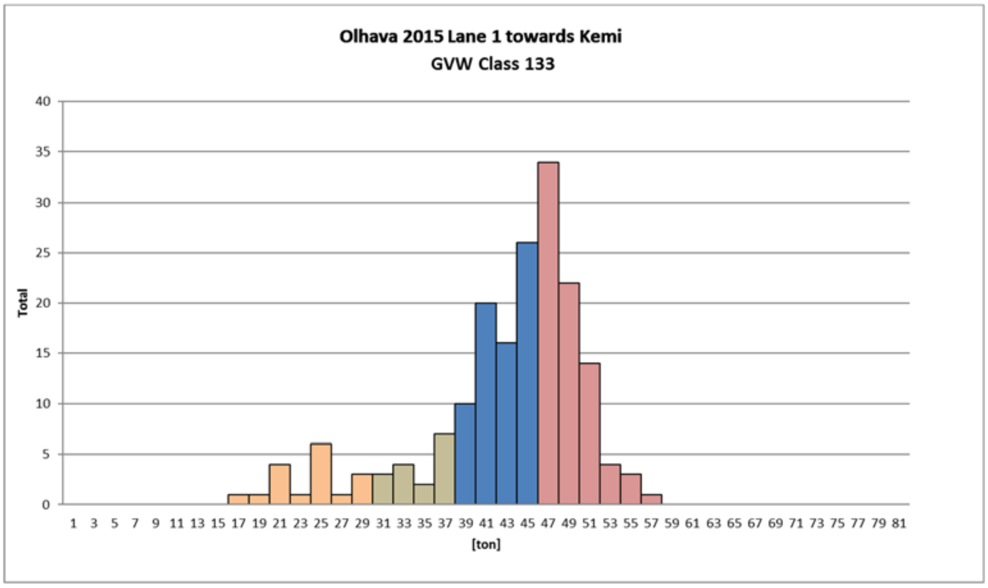




*Figure 110. GWV frequency of class 130 vehicles, lanes 1 and 2.*

*Table 103. Average axle weight per sector and totals class 133 (1-2-3) for lanes 1 and 2.*

| Average Axle Weight per Sector and Totals Class 133 (1-2-3) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Count | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 |
| Lane 1 | Sector 1 | 17 | 6.059034 | 4.595621 | 4.595621 | 3.284086 | 3.284086 | 3.284086 |
| | Sector 2 | 16 | 6.288144 | 6.418158 | 6.418158 | 5.499011 | 5.499011 | 5.499011 |
| | Sector 3 | 72 | 6.555161 | 7.688278 | 7.693249 | 7.234731 | 7.234731 | 7.234731 |
| | Sector 4 | 78 | 6.706138 | 9.045824 | 9.045824 | 8.37621 | 8.37621 | 8.37621 |
| | Total | 183 | 6.550077 | 7.868559 | 7.870515 | 7.202506 | 7.202506 | 7.202506 |
| | | | | | | | | |
| Lane 2 | Sector 1 | 6 | 6.453444 | 3.765982 | 3.765982 | 3.013771 | 3.013771 | 3.013771 |
| | Sector 2 | 12 | 6.387077 | 6.266751 | 6.266751 | 5.19316 | 5.19316 | 5.19316 |
| | Sector 3 | 54 | 6.470477 | 7.791123 | 7.791123 | 7.292803 | 7.292803 | 7.292803 |
| | Sector 4 | 38 | 6.862824 | 8.939503 | 8.939503 | 8.295445 | 8.295445 | 8.295445 |
| | Total | 110 | 6.595988 | 7.801988 | 7.801988 | 7.176716 | 7.176716 | 7.176716 |
| | | | | | | | | |
| | Total All | 293 | 6.567313 | 7.794062 | 7.794062 | 6.875576 | 6.875576 | 6.875576 |



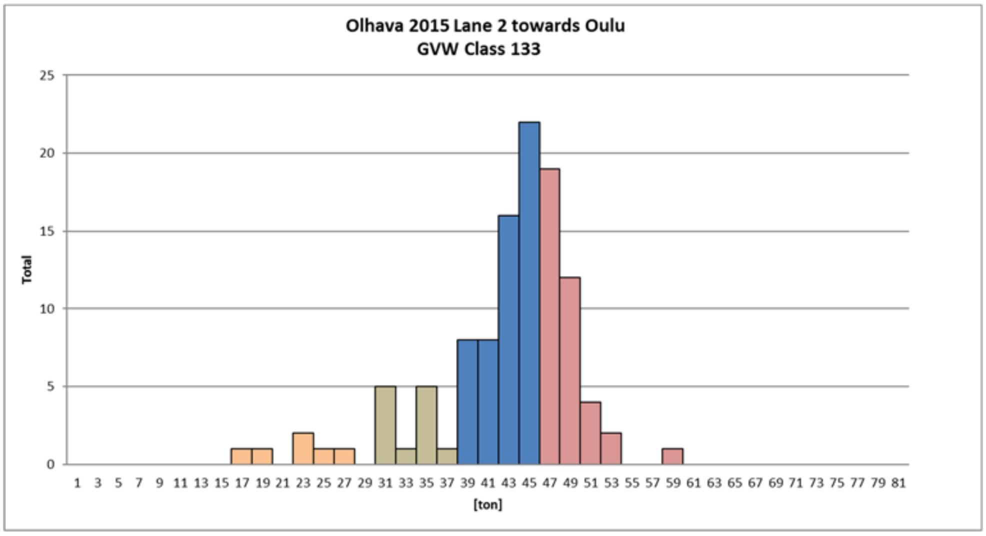
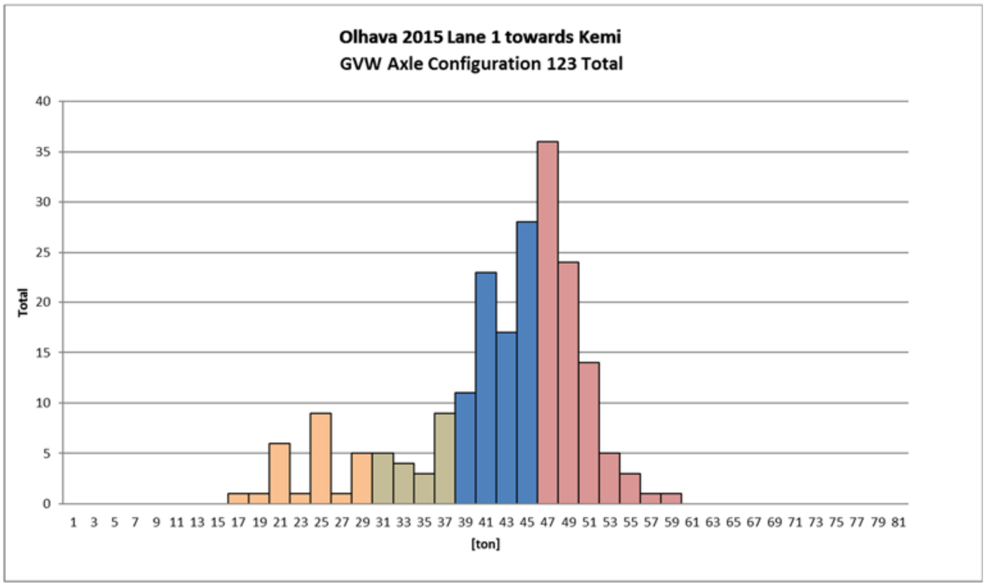




*Figure 111. GWV frequency of class 133 vehicles, lanes 1 and 2.*

*Table 104. Average axle weight per sector and totals axle configuration 1-2-3 for lanes 1 and 2.*

| Average Axle Weight per Sector and Totals Axle Configuration 1-2-3 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Count | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 |
| Lane 1 | Sector 1 | 19 | 5.758445 | 3.848463 | 3.848463 | 3.006284 | 3.006284 | 3.006284 |
| | Sector 2 | 26 | 6.513751 | 6.289021 | 6.289021 | 5.475366 | 5.475366 | 5.475366 |
| | Sector 3 | 79 | 6.523125 | 7.676282 | 7.680812 | 7.239211 | 7.239211 | 7.239211 |
| | Sector 4 | 84 | 6.68424 | 9.075559 | 9.075559 | 8.389217 | 8.389217 | 8.389217 |
| | Total | 208 | 6.517168 | 7.71831 | 7.720031 | 7.096494 | 7.096494 | 7.096494 |
| | | | | | | | | |
| Lane 2 | Sector 1 | 6 | 6.398428 | 3.802085 | 3.802085 | 3.27125 | 3.27125 | 3.27125 |
| | Sector 2 | 14 | 6.431059 | 6.225732 | 6.225732 | 5.095012 | 5.095012 | 5.095012 |
| | Sector 3 | 56 | 6.440491 | 7.769782 | 7.769782 | 7.316172 | 7.316172 | 7.316172 |
| | Sector 4 | 42 | 6.933876 | 9.033277 | 9.033277 | 8.32035 | 8.32035 | 8.32035 |
| | Total | 119 | 6.611043 | 7.800675 | 7.800675 | 7.171338 | 7.171338 | 7.171338 |
| | | | | | | | | |
| | Total All | 327 | 6.551331 | 7.748284 | 7.749379 | 7.123731 | 7.123731 | 7.123731 |



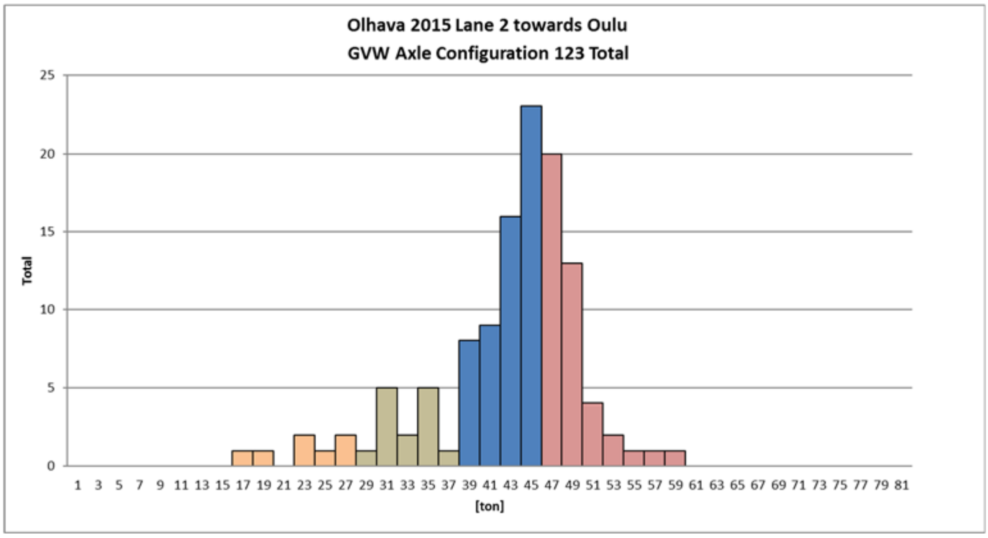




*Figure 112. GWV frequency of axle configuration 1-2-3 total, lanes 1 and 2.*

## 5.4 Vehicle types

From all the above analyses, the changing shape of the traffic and vehicle configuration is constantly developing subsequent to the introduction of the Finlex regulations.

These effects are becoming more commonplace as haulers either adapt existing vehicles in line with the regulations or purchase new ones. By consideration and analysis of the class 140 vehicles, the classification table can be constantly up-dated to compensate for the changes in vehicle configuration.

However, the number of vehicles that can be classified is limited, and to this end Trafikia AB and Cestel d.o.o. have developed an excel calculation worksheet which can analyze a myriad of different vehicle configurations.

This is an especially important tool when trucks with 8, 9, 10 and more axles are introduced to the network. Yearly measurements will prove this trending and loading models can be produced from the collected data, together with LAM automatic traffic counter factoring.

# 5.5 Tyre compensation factors

Because pneumatic tyres are flexible, the contact patch is different when the vehicle is in motion from when it is static. Because it is so much easier to make observations of the contact patch without the tyre in motion, it is more common to conduct studies of the static contact patch.

Statistically, the size, shape, and pressure distribution are functions of many things, the most important of which are the load on the tyre and the inflation pressure.

- The larger the load on the tyre, the larger the contact patch.
- The larger the inflation pressure, the smaller the contact patch.

Unfortunately, these two properties are not linearly proportional to the area of the contact. For example, a 10% change in load or inflation pressure usually does not result in a 10% change in the contact patch area, because the load or pressure of a tyre can be altered freely, and the contact patch area is limited by the tire geometry.

Further, the size of the contact patch cannot be simply calculated as load divided by inflation pressure, and the average contact pressure a tyre has with the road surface is not equal to the inflation pressure.

In summary both load and pressure have a bearing on the size of the contact area. How significant this property is when analyzing pavement and structural deformation is a complex and very difficult process.

The SiWIM system does not evaluate the number of tyres per axle, but written into the classification table sub-text is an *assumed* configuration for each of the vehicle types. Although this is not a comprehensive and definitive method, it goes some way to correcting potential ESAL calculation problems.

For example:

```
[subclass_100]
category=3
max_GVW__kN=558.97
tyre_type=1,2,2,1,1,1,1
max_axle_weight__kN=1,98.07;2,88.26;3,88.26;4,98.07;5,78.45;6,78.45;7,78.45
max_axle_distance__m=6.0,1.75,9.0,8.0,1.35,1.25
min_axle_distance__m=2.2,0.9,3.0,1.5,0.9,0.9
number_of_axles=7
```

Where Tyre type is defined as: 1=single, 2=double, 3=super single, 4=quadruple.

# 6 Conclusions

## 6.1 Esal comparisons

In the ESAL section of this report (4.1), we have endeavored to clarify how the ESAL calculations are made using the SiWIM system. This study has been completed in co-operation with Destia OY, and from their published articles, we can see that the methods of calculation are dissimilar. Factoring the results is one solution to producing quantitative values, but the methodology of the two systems are very unlike where the Destia method is by pre-selection of vehicles and the B-WIM system measures all traffic. We have shown in previous reports and presentations why there are variables, and this could be reviewed in a further consultative document.

When comparing year to year, especially when the measures have been continuous as for Olhava, it is noticeable that there is a fall in the number of 7 axle vehicles and an increase in 8, 9 & 10 axle vehicles. This shows that haulage companies are embracing the new regulations and increasing their vehicle's capacities with additional axles. This trend can be seen in the increase in GVW's. It should be noted that all the figures produced are **averages** based on all data for each site and axle configuration. If for example, we examined only the vehicles above the mean point in each configuration and tabulated the results for number of vehicles and GVW's, we can see similar trends, figures 113 and 114. In the GVW diagram for 8, 9 & 10 axles, the "average" produced in figure 114 (being all vehicles above the mean average in each axle group) for 2015 & 2016 shows in excess of 60t, 70t and 75-80t which is an extreme statistic. Future monitoring of these trends is vital to keep control.

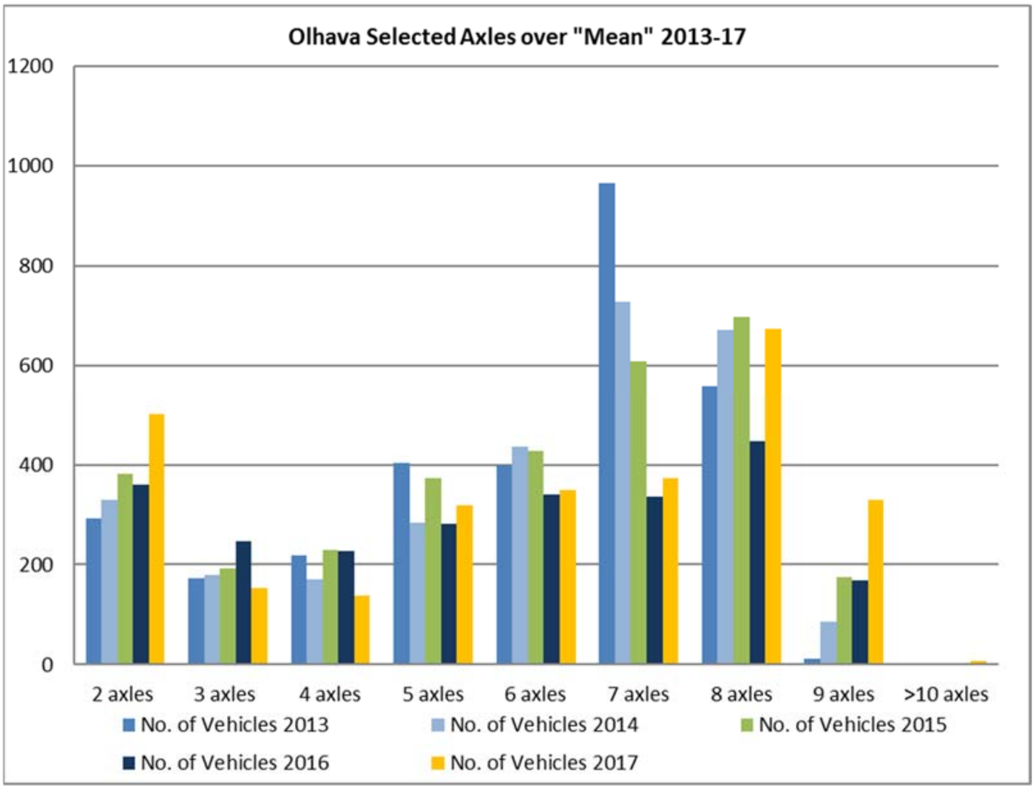



*Figure 113. Olhava selected axles over mean point, number of vehicles 2013-2017.*

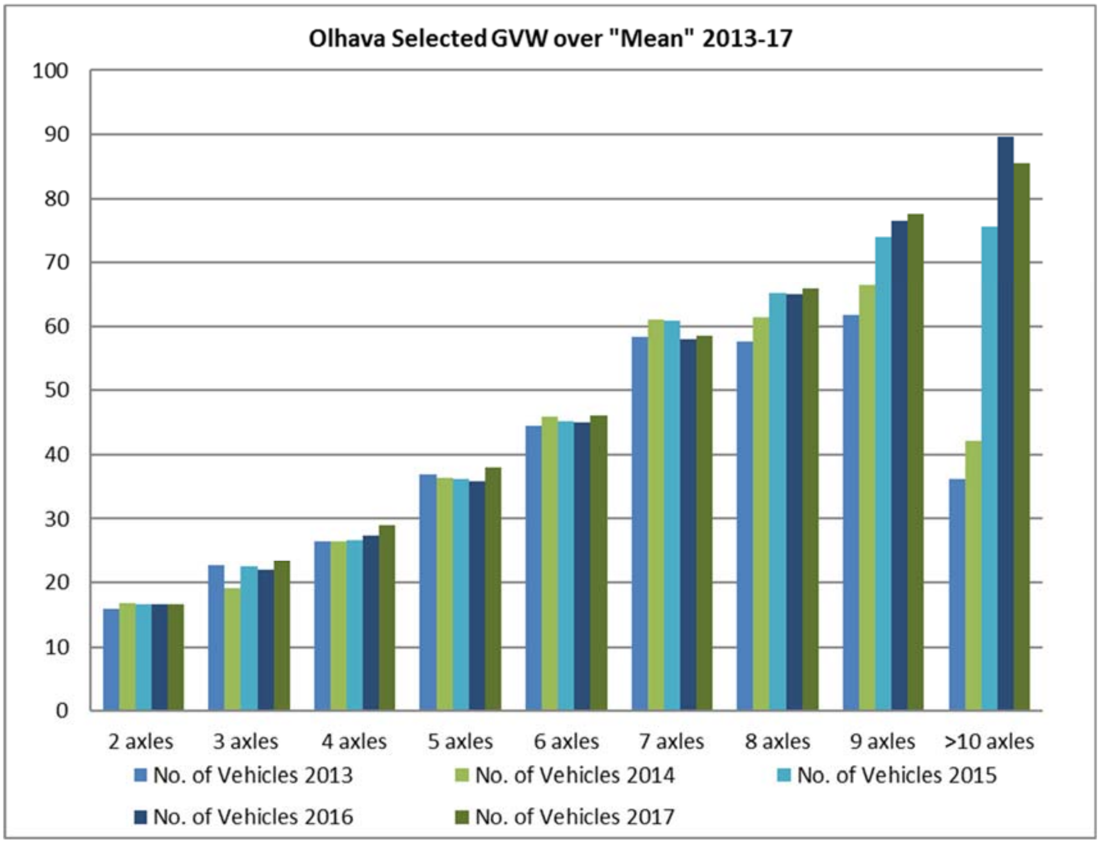



*Figure 114. Olhava selected GVW over mean point, 2013-2017.*

## 6.2 Vehicle classes now/future updates

As described in the reports above, the trend and development of new vehicle configurations is continuous, as more haulers take advantage of the new regulations. Only by careful monitoring of the traffic network can these new classifications be detected. Trafikia AB have developed a classification table that encompasses most vehicle configurations, but this table requires constant updating to meet the demands of the changing pattern of vehicles.

## 6.3 Future measurements, network e.g.

Earlier in this document, proposals for future measurements were indicated. Full coverage of the entire Finnish road network is an awesome task and an expensive undertaking, but with the secure knowledge that the present infrastructure can cope with future demands, this investment is worthwhile. Traffic modelling based on collected B-WIM data and factored with LAM (automatic traffic counters) gives assurances and confidence levels on the current network, and adversely indicates potential problems.

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